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Potential Use of Native and Naturalized Insect Herbivores and Fungal Pathogens of Aquatic and Wetland Plants

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Abstract: Research is being conducted by U.S. Army Engineer Research and Development Center (ERDC) scientists to identify naturalized and/or native herbivores of aquatic plants in an effort to develop alternative management strategies through an understanding of the agents' biology and ecology. Some of the native species showing promise as biocontrol agents include *Altica* spp. for water primrose, *Donacia* spp. for American lotus, and *Euhrychiopsis lecontei* for Eurasian watermilfoil control. Naturalized species with possibility include *Cyrtobagus salviniae* for common and giant salvinia, and *Parapoynx diminutalis* for hydrilla. Information is presented herein for selected native and naturalized agents that may potentially be used to impact and manage all types of aquatic and wetland plant species including introduced, naturalized, and native species. Native and naturalized insect herbivores and fungal pathogens discussed include: *Acanthoscelides quadridentatus*, *Acentria ephemerella*, *Altica* spp., *Cyrotobagous salviniae*, *Donacia* spp., *Euhrychiopsis lecontei*, *Hydrellia bilobifera* Cresson, *H. discursa* Deonier, *Mycoleptodiscus terrestris*, *Ostrinia penitalis*, *Parapoynx diminutalis*, *Pergaster cretura*, Simyra *henrici*, and *Synclita oblieralis*.

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 33189. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC), under the purview of the Environmental Laboratory (EL). Funding was provided under the Department of the Army Appropriation No. 96X3122, Construction General. Robert C. Gunkel, Jr., EL, was Program Manager, APCRP. Program Monitor during this investigation was Timothy R. Toplisek, HQUSACE.

The principal investigator for this study was Dr. Michael J. Grodowitz, Aquatic Ecology and Invasive Species Branch, Ecosystem Evaluation and Engineering Division (EEED), EL. This report was prepared by Jan E. Freedman, Dr. Michael J. Grodowitz, Robin Swindle, and Julie G. Nachtrieb. At the time of preparation, Robin Swindle was located at Baylor University, Waco, TX. Julie Nachtrieb is located at ERDC, Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX. The report was reviewed by Dr. Judy Shearer, EEED, and Chetta S. Owens, Analytical Services, Inc., LAERF.

This investigation was performed under the general supervision of Dr. Elizabeth C. Fleming, Director, EL; Dr. David J. Tazik, Chief, EEED, and Dr. Andrew C. Miller, former Branch Chief, Aquatic Ecology and Invasive Species Branch.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Many aquatic and wetland plant species cause tremendous problems across the country. These include impacts to biodiversity, navigation, irrigation, increased evaporation, as well as human health hazards (Anderson et al. 2005). Traditional control methods are varied and include management options such as chemical and mechanical strategies. While these methods produce satisfactory short-term control, other alternative methods that produce long-term and wide-scale impacts have been developed.

Alternative methods used to date have included the use of insect and fungal agents. Prime examples are the use of flea beetles for the management of alligatorweed (*Alternanthera philoxeroides* [Mart.] Griseb.), weevil species in the genus *Neochetina* to provide management for waterhyacinth (*Eichhornia crassipes* [Mart.] Solms.-Laubach), and the use of leaf-mining flies in the genus *Hydrellia* for hydrilla (*Hydrilla verticillata* (L.f.) Royle) control. In addition, progress has been made on the use of the fungal pathogen *Mycoleptodiscus terrestris* (Gerd.) Ostazeski for both hydrilla and Eurasian watermilfoil (*Myriophyllum spicatum* L.) management.

While traditional control methods have been employed successfully for introduced, native, and naturalized plant species, almost all biological control techniques are only directed towards introduced plant species. Most biological control projects involve exotic or introduced plant species that were accidentally or intentionally introduced into new environments minus their natural enemies. The goal of such projects is not eradication, but the reduction of a plant's abundance to a lower, more tolerable level (Goeden 1977). The process of obtaining biocontrol agents involves the importation (from the country of origin of the plant) and establishment of host-plant specific, crop-safe, plant-destructive natural enemies (Goeden 1977).

One of the fundamental concepts of biocontrol is that introduced and possibly native/naturalized agents damage nuisance, invasive plants, thus slowing their growth (Goeden 1977). With a decrease in growth and growth potential, native plants can compete more favorably with the invasives. Classical biological control is based on the strategy that collecting natural enemies, i.e. parasites, predators, or pathogens of an invasive plant from its country of origin, and then releasing these organisms in places

where it has become a nuisance will keep the plant's growth in check (Harley and Forno 1992). Identifying and obtaining these organisms is a lengthy process. It requires years of overseas research and extensive host testing to ensure that they are safe and will not attack any native, agronomic, or other plants deemed important in their introduced region (Harley and Forno 1992).

Traditionally these agents are from the same country as the invasive plant. In some cases, however, there are native or naturalized insects or pathogens already existing in the plant's introduced range that may help keep the invasive plant's growth below an economic threshold. The question becomes as to whether native or naturalized organisms would be successful biological control agents for introduced, nuisance plants. Equally important is whether native or naturalized agents are available to manage native and/or naturalized aquatic and wetland plant species.

2 Purpose of Studying Native and Naturalized Insect Herbivores and Fungal Pathogens of Aquatic and Wetland Plants

In addressing this issue, aquatic nuisance species program managers from Minnesota, Vermont, and Washington took part in a panel discussion on the "Management of Eurasian Watermilfoil in the United States Using Native Insects: State Regulatory and Management Issues" in 1998 (Madsen et al. 2000). While this panel specifically addressed Eurasian watermilfoil (EWM) issues, their ideas had wide application to the use of native and naturalized organisms for other species as well. The panel identified several positive and negative attributes for using native organisms. The use of native organisms: (1) is more popular with the general public than the use of exotic organisms (e.g., classical biological control) or herbicides; (2) generally requires fewer regulatory steps; (3) is desirable if a selective and cost-effective biological control can be found; (4) is feasible if a cost-effective method of propagation and distribution can be found; and (5) holds the promise for long-term control. Drawbacks included: (1) no state is prepared to embark on large-scale rearing of organisms for widespread distribution; (2) states are concerned about the introduction of new exotic pest species or insect parasites or pathogens brought in with the organisms from outside of the state; and (3) states are concerned about the introduction of more aggressive genotypes or other genotypes that may have less desirable attributes (e.g. lower fecundity or feeding rates). Additionally, the panel agreed that before native organisms could be widely used for managing nuisance aquatic plants, three issues needed to be addressed: (1) larger sources of these organisms are needed; (2) a practical approach needs to be developed to utilize native organisms that is both cost-effective and efficacious; and (3) consistent permitting or regulatory criteria need to be developed between states and at the federal level. Therefore, it is important to understand what impacts potential native/naturalized herbivores are having not only on invasive species but on native plants as well. By doing so, biocontrol researchers can begin to:

1. *Identify naturalized herbivores with potential as alternative agents for the control of introduced plants:* Naturalized insects are those not native to this country but were accidentally released along with the host plant and

have been in the country for such an extended period that they are now considered part of the ecosystem. The Asian hydrilla moth, (*Parapoynx diminutalis* Snellen), known from Pakistan to Southeast Asia (Delfosse et al. 1976), is considered to be a naturalized species in the U.S. It was found in Pakistan in 1973 and was considered to be a potential biocontrol agent for hydrilla in the U.S. (Buckingham and Bennett 1989, Balciunas et al. 2002). In 1976, however, it was reported feeding on hydrilla in south Florida, spreading rapidly causing extensive damage to the plants (Delfosse et al. 1976, Balciunas and Habeck 1981, Balciunas et al. 2002). It was likely introduced into the state through the aquarium industry (Balciunas et al. 2002), and could potentially be reared in large numbers to be used as a hydrilla biocontrol agent. In addition, the prime insect biocontrol agent for giant salvinia (*Salvinia molesta* D. S. Mitchell), the salvinia weevil (*Cyrtobagous salviniae* Calder and Sands), has been naturalized in the U.S. on common salvinia (*Salvinia minima* Baker) for years (Center et al. 1999) and offers potential for the control of both species in many areas of the country.

2. *Develop native insect herbivores for use as biocontrol agents of native plants:* For example, water-primrose (*Ludwigia grandiflora* (Michaux) Zardini, Gu, and Raven), although native to North and South America, is considered to be a nuisance plant in most of its range (Balsbaugh and Hays 1972, Aurand 1982, Chester and Hold 1990, McGregor et al. 1996). The water-primrose flea beetle (*Altica ludoviciana* (Fall)) (syn. *Lysathia ludoviciana* (Fall)) is a natural enemy of water-primrose and can devastate stands of primrose if present in sufficient quantities. This insect would be a prime candidate as a potential biocontrol agent once more information is obtained concerning host specificity, biology, and the ability for mass-rearing. Another potential candidate for water-primrose management includes the native water-primrose leaf weevil (*Perigaster cretura* (Herbst)).
3. *Understand the role native herbivores have on native plant growth, reproduction, etc.:* It has been documented that one reason native plants can not effectively compete with introduced species such as hydrilla and EWM is that there is a large assemblage of native herbivores and pathogens attacking the native species that significantly slows their growth and reproduction (Berg 1949, Wiggins 1977, Carpenter and Lodge 1986, Newman 1991, Cronin et al. 1998). Recent studies have shown that hydrilla invasions and subsequent expansions can be slowed significantly if native plants are well established in the area (Smart 1992, Smart 1993, Smart et al. 1994). In addition, the combined use of native plantings coupled with the release of the hydrilla leaf-mining flies can provide even better control

than either method used alone (Grodowitz et al. 2007). Since plant competition is an important component for success when using hydrilla biocontrol agents, it is important to understand the whole range of biological factors that are impacting native plant species, especially the role of native herbivores and pathogens.

4. *Understand native herbivores ecology, biology, host-specificity, and mass-rearing, to aid other countries with emerging plant problems:* Many U.S. native plants have been transported to other countries and are now becoming invasive, including fanwort (*Cabomba caroliniana* Gray) in Australia (Mackey and Swarbrick 1997, Ensbey 2000, Schooler et al. 2005), coontail (*Ceratophyllum demersum* L.) in New Zealand (Wells et al. 1997, ISSG Global Invasive Species Database 2006), and pennywort (*Hydrocotyle ranunculoides* L. f.) in England (*English Nature* 1999, Newman and Dawson 1999, Newman 2004). By understanding the native herbivores of fanwort (or of any U.S. native plants that have become problems in other countries), one could aid them in finding and developing biological agents for these nuisance plants.

Information is presented herein concerning examples of native and naturalized agents that may potentially be used to impact and manage all types of aquatic and wetland plant species including introduced, naturalized, and native species. Information for each species includes a brief description, introduction history (if applicable), scientific, nomenclature and common name (if available), photographs (if available), general information and life history, biology, host-specificity, and operational status including research needed before deciding on the organism's usefulness. The amount of information for each organism varies because some have been studied extensively while only limited information exists for others.

3 Native and Naturalized Insect Herbivores and Fungal Pathogens of Aquatic and Wetland Plants

Information is presented herein for selected native and naturalized agents that may potentially be used to impact and manage all types of aquatic and wetland plant species including introduced, naturalized, and native species. Native and naturalized insect herbivores and fungal pathogens discussed include: *Acanthoscelides quadridentatus*, *Acentria ephemerella*, *Altica* spp., *Cyrotobagous salviniae*, *Donacia* spp., *Euhrychiopsis lecontei*, *Hydrellia bilobifera* Cresson, *H. discursa* Deonier, *Mycoleptodiscus terrestris*, *Ostrinia penitalis*, *Parapoynx diminutalis*, *Pergaster cretura*, Simyra *henrici*, and *Synclita oblieralis*.

Acanthoscelides quadridentatus (Schaeffer) – Mimosa Seed Beetle (Coleoptera: Bruchidae) (Figure 1)

Figure 1. Mimosa seed beetle adult, eggs, and adult appearing in an exit hole.
(Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

The Mimosa seed beetle's (*Acanthoscelides quadridentatus* (Schaeffer)) distribution includes Texas, Mexico, Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, Panama, and South America (Johnson 1983). Catclaw mimosa or giant sensitive plant (*Mimosa pigra* L. (Fabaceae)) was possibly introduced into Florida as early as 1926 (Fairchild 1944). The extensive canals and wetlands of southern Florida are similar to the habitats that have been invaded by catclaw mimosa elsewhere

(McCann et al. 1996). In 1990, Schardt and Schmitz reported the plant was spreading rapidly and believed the species might rival melaleuca's ability to invade the Everglades. The high reproductive potential of catclaw mimosa and the persistence of its seeds in the soil account for its weedy nature (Lonsdale et al. 1988). Seed banks in Australia can contain 12,000 seeds/m^2, two orders of magnitude higher than in Mexico, which is within its native range (Lonsdale et al. 1988). This led the Australians to consider the introduction of seed predators (Harley 1985). Two bruchid species, *A. quadridentatus* (Schaeffer) and *A. puniceus* (Johnson), were released in 1983 (Kassulke et al. 1990).

Biology

The adults are small, brownish beetles (Figure 1 - Adult). The females lay their eggs on mature seed pods (Figure 1 - Eggs) and upon hatching, the larvae bore into the seeds to complete their development (U.S. Army Engineer Research and Development Center (ERDC) 2005 Aquatic Plant Information System (APIS)). Each larva develops within a single seed (Center et al. 1999). Larval feeding causes the seed to become completely hollowed out which makes it nonviable (Center et al. 1999). Once the larvae finish development and pupate, the adults emerge through little round holes cut in the seed (Figure 1 - Adult and exit hole) (Borror et al. 1976).

Host-Specificity

There have been no studies describing the impacts of this insect on its host plants (Center et al. 1999).

Research/Impact

According to Center and Kipker (1991), research/surveys were conducted during 1986 by biologists from the Florida Department of Natural Resources. Catclaw mimosa seeds were collected at infested Florida sites. Beetles later emerged from some of the seeds including those collected 10 July 1986 at a pepper farm located 10 km west of Jupiter (Martin County) and were positively identified as *A. quadridentatus*. Seeds were later collected at the same site on several dates between June and December 1989 to verify this record. Once again, *A. quadridentatus* emerged from some of the seeds; however, these bruchids destroyed only a small portion of the seed crop during this period (average < 1 percent, maximum 4.4 percent). Apparently adults could remain within hollowed-out seeds

for extended periods. The site was going to be monitored further to determine if infestation rates varied seasonally. Unfortunately, the plants were destroyed by herbicide treatment. Samples were also collected in Saint Lucie County at two sites, the St. Lucie River and the C-23 canal, in 1989 but no bruchids emerged from the seeds.

Possible Use in Control Programs

Acanthoscelides quadridentatus could potentially be a useful biocontrol agent and would reduce seed quantities of catclaw mimosa if the insects were allowed to reach high enough population levels. However, this species makes up less than 3 percent of the beetles reared from field-collected catclaw mimosa seeds and, therefore, is unlikely to have any major effect on the plant populations, especially where seed production is very seasonal (Julien and Griffiths 1999). More information is needed describing factors that are limiting their increase in the U.S. and the potential for development of mass-rearing and introduction programs.

Acentria ephemerella Denis and Schiffermuller (syn: *Acentria nivea* Oliver) – Milfoil Moth, Water Veneer Moth (Lepidoptera: Pyralidae) (Figure 2)

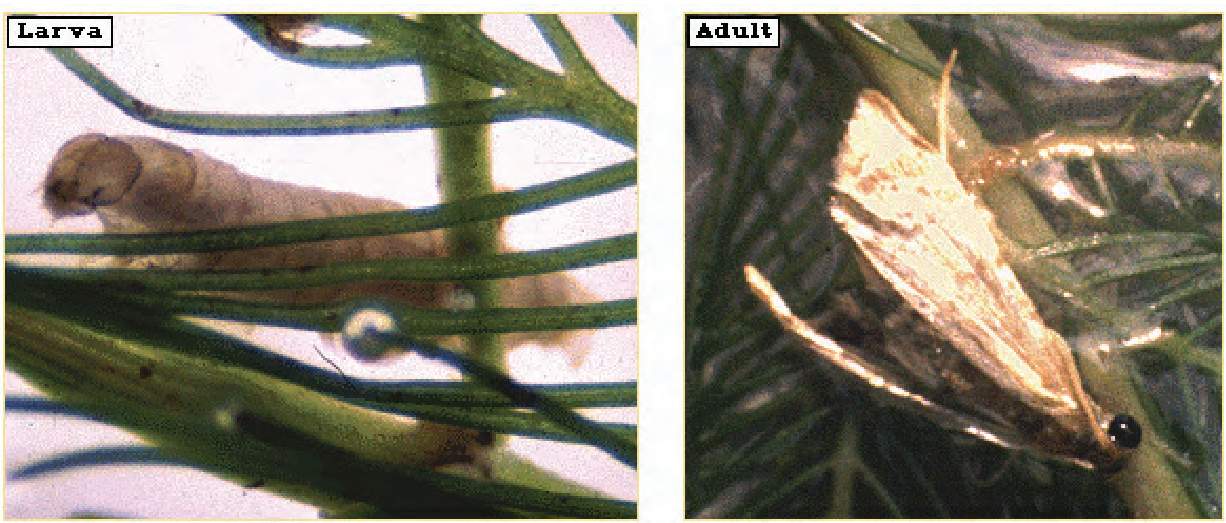

Figure 2. Milfoil moth larva and adult. (Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

Acentria ephemerella Denis and Schiffermuller, is an aquatic moth from Europe that was first reported in North America near Montreal in 1927 (Sheppard 1945). It is believed that this species was accidentally

introduced to North America through the shipping trade (VanDusen 2003). Today this moth can be found from Massachusetts to Iowa and has been associated with declines of EWM, in Ontario, Canada, and New York (Johnson and Blossey 2002).

Biology

The milfoil moth is one of the few moth species that completes almost its entire life cycle underwater (VanDusen 2003). Females lay their eggs near the bottom of EWM plants and after they hatch, the larvae crawl up the plant to feed on growing tips (Figure 2 - Larva) (Northern New York Agricultural Program 1999). The larvae move about the plant eating the tips as they complete their five instar stages (Northern New York Agricultural Program 1999). The males emerge from the water for a brief day or two to conduct a courtship flight (Figure 2 - Adult). Most females are wingless and float on the surface of the water waiting to attract a mate (VanDusen 2003). Once the females have mated, they dive down into the water to lay their clutch of eggs, which ranges from 100 to 300 eggs per clutch. Winged females usually lay less than 100 eggs per clutch (VanDusen 2003).

Host-Specificity

In initial host-specificity tests conducted in the 1970's, milfoil moth larvae fed on almost all test plants offered to them, which reduced interest in use of this insect as a potential biocontrol agent for EWM (Buckingham and Ross 1981). Recent declines of EWM associated with the milfoil moth, however, have caused a reevaluation of the usefulness of this insect as a potential biological control agent (Johnson and Blossey 2002).

Research/Impact

A twelve-year study conducted at Cayuga Lake, New York, looked at aquatic plant biomass and showed a dramatic decline of EWM associated with large populations of the milfoil moth (Johnson et al. 1998, Gross et al. 2001). In the summer of 1997, a five-lake survey in New York was conducted to explore the relationship between lake size, abundance of EWM, and EWM herbivore numbers (Johnson et al. 2000). Data were collected from five lakes (Cayuga, Dryden, Keuka, Lamoka, and Waneta). Observations from the five-lake survey concluded that milfoil moth densities have a highly significantly negative correlation with percentage composition

and total dry mass of EWM (Johnson et al. 2000). Also, the decline of EWM associated with the milfoil moth in Cayugua Lake suggests that this insect may be an effective long-term biological control agent (Johnson et al. 2000).

Possible Use in Control Programs

In some areas of New York, the mass production of the milfoil moth and procedures for its release and evaluation have been undertaken (Hairston and Johnson 2001), but more work is needed.

Altica spp. – Flea Beetles; Leaf-Feeding Beetles; Water-Primrose Flea Beetle (Coleoptera: Chrysomelidae: Halticinae) (Figures 3-5)

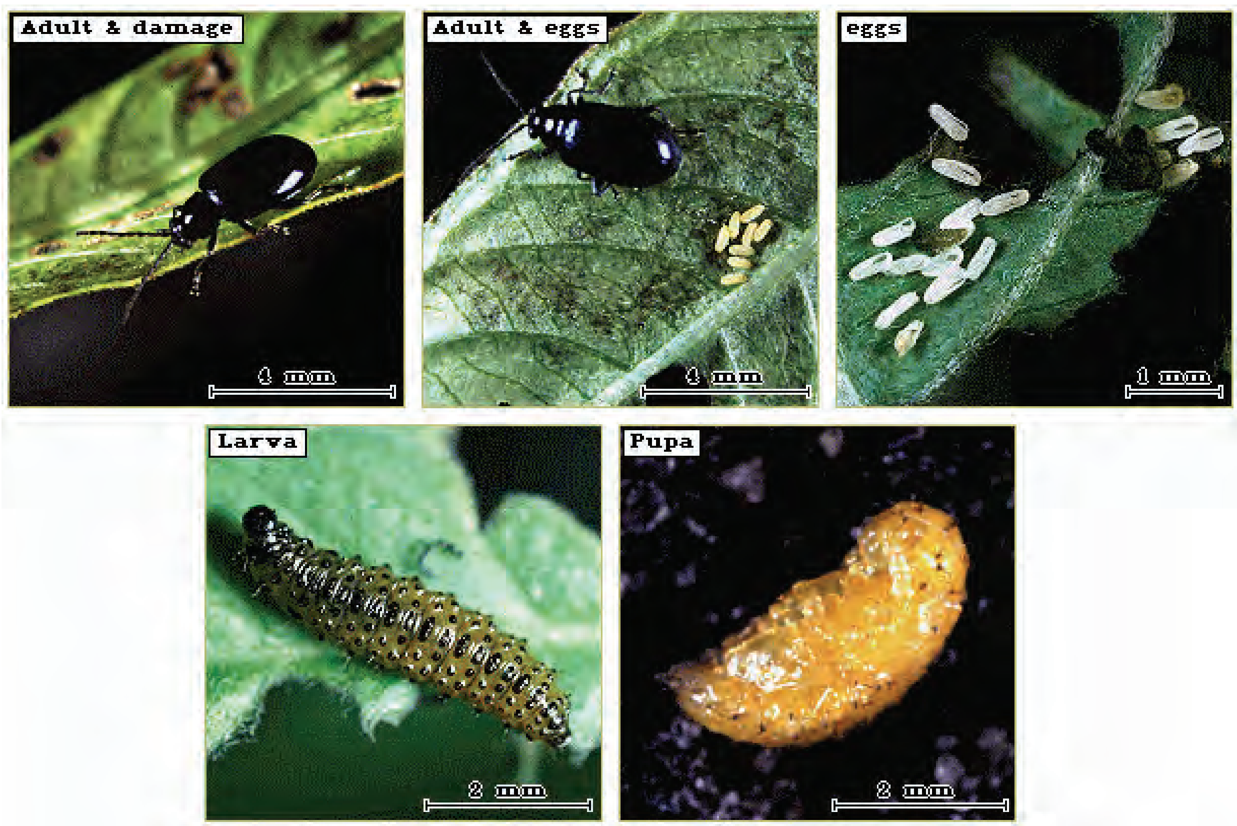

Figure 3. *Altica litigata* Fall - Water-Primrose Flea Beetle adult damage, adult and eggs, eggs, larva, and pupa. (Photographs courtesy of the ERDC, 2005, APIS.)

Figure 4. Water-primrose flea beetle adult and larvae. (Photographs courtesy of Dr. Michael J. Grodowitz, ERDC, September 2004.)

Figure 5. Primrose damaged by water-primrose flea beetle. (Photograph courtesy of Dr. Michael J. Grodowitz, ERDC, September 2004.)

General Information and History

Flea beetles are small jumping leaf beetles that have enlarged hind femora (Borror et al. 1976). Most of them are blue or greenish, but many are black or black with light markings (Borror et al. 1976). Many of them are important pests of garden and field crops, but several have been studied as potential biocontrol agents of nuisance plants. Water-primrose (*Ludwigia* spp.), although native to North and South America, has been considered a

nuisance plant in most of its range (Balsbaugh and Hays 1972, Aurand 1982, Chester and Hold 1990, McGregor et al. 1996). The natural hosts of the water-primrose flea beetle (*Altica ludoviciana* (Fall)) (syn. *Lysathia ludoviciana* (Fall)) include water-primrose, parrotfeather (*Myriophyllum aquaticum* (Velloso) Verde) (Habeck and Wilkerson 1980, Washington State Department of Ecology 2003), and creeping water primrose (*L. peploides* (H.B.K.) Raven) (McGregor et al. 1996).

The water-primrose flea beetle has also been studied at Auburn University in Alabama as a potential biological control of Uruguay waterprimrose (*L. uruguayensis* (Camb.) Hara) (McGregor et al. 1996; USDA, NRCS 1999). The water-primrose flea beetle (*Altica litigata* Fall) has been found to feed on another water-primrose (*L. octovalvis* (Jacq.) Raven), waterpurslane (*L. palustris* (L.) Ell.) (Center et al. 1999), and purple loosestrife (*Lythrum salicaria* L.), an invasive, exotic, wetland plant that replaces native species and clogs waterways (Hoyme et al. 2001). *Altica foeveicollis* Jacoby, an endemic species of flea beetle in Thailand, has been a very effective natural control of the water-primrose (*L. adscendens* L. Hara) and other *Ludwigia* spp. in Thailand (Napompeth 1994, Julien and Griffiths 1999). At the Department of Zoology, Burdwan University, India, Nayek and Banerjee (1987) are testing *Altica cyanea* as a potential biological control agent. The country of Malaysia is particularly interested in using this beetle to help control *L. adscendens* growing as a weed in rice-paddies (Nayek and Banerjee 1987).

Biology

Altica litigata Fall adults are shiny metallic green, ca. 4 mm in length (Figure 3 - Adult and damage, adult, and eggs). Female *A. litigata* lay yellowish, oblong eggs in groups on the leaf surface (Figure 3 - Adult and eggs, eggs). The larvae have a greenish-yellow body with a black head capsule and distinctive black plates on their bodies (Figure 3 - Larva) (Center et al. 1999). The larvae burrow into the soil to pupate (ERDC, 2005, APIS). The yellow pupa are found close to the soil surface in a loosely constructed chamber (Figure 3 - Pupa) (ERDC, 2005, APIS). Larvae and adults feed on the leaves of plants causing irregular holes in the foliage followed by foliar scraping by the larvae (Schultz et al. 2001). *Altica ludoviciana* are ca. 4-5 mm in length, and are dark brown with a bluish-black appearance. They are differentiated from other beetles by their greatly enlarged hind femora (McGregor et al. 1996) and their enlarged yellowish-brown legs (Habeck and Wilkerson 1980). Flea beetle feeding by both lar-

vae and adults causes skeletonizing of the foliage and eventual leaf drop (Figures 4 and 5) (Schultz et al. 2001).

Research/Impact

A two-year study initiated in 2000 by the University of Tennessee, Department of Entomology and Plant Pathology, Knoxville, TN, assessed the impact of *A. litigata* on leaf consumption and seed production of purple loosestrife in eastern Tennessee (Hoyme et al. 2001). The researchers found that larval feeding was extensive and caused the foliage to appear skeletonized, thus reducing seed production and the number of seeds per capsule.

Possible Use in Control Programs

Two *Altica* spp. have shown potential for use in aquatic weed management programs, *A. litigata* on purple loosestrife, and *A. ludoviciana* on *L. uruguayensis*. Hoyme et al. (2001) witnessed a large population of *A. litigata* feeding on purple loosestrife greatly impacting the plant's production of seed capsules and seeds. From this positive activity, Hoyme et al. (2001) felt that *A. litigata* would prove to be a potential agent for purple loosestrife. Researchers at Auburn University Fisheries Research Field Station, Auburn, AL (1996), have studied the effects of *A. ludoviciana* on *L. uruguayensis*. Changes in aquatic macrophyte communities and insect abundance in six littoral enclosures (5 x 10 m) where a population of *L. uruguayensis* had been colonized by *A. ludoviciana* were quantified (McGregor et al. 1996). Water primrose dry weight biomass declined during the four sampling times taken from July to September. The flea beetles were sampled nine times between July and October, and although the abundance was variable there were three peaks in abundance on 15 July, 5 August, and 30 September. In the spring of 1995, no beetles were found within the enclosures (McGregor et al. 1996). More research is needed on *Altica* spp. taxonomy, biology, seasonality, and host-specificity. Coinciding with this basic work is the need to develop efficient mass-rearing procedures.

Cyrtobagous salviniae Calder and Sands, Salvinia Weevil (Coleoptera: Curculionide: Curculioninae: Erirhinini) (Figure 6)

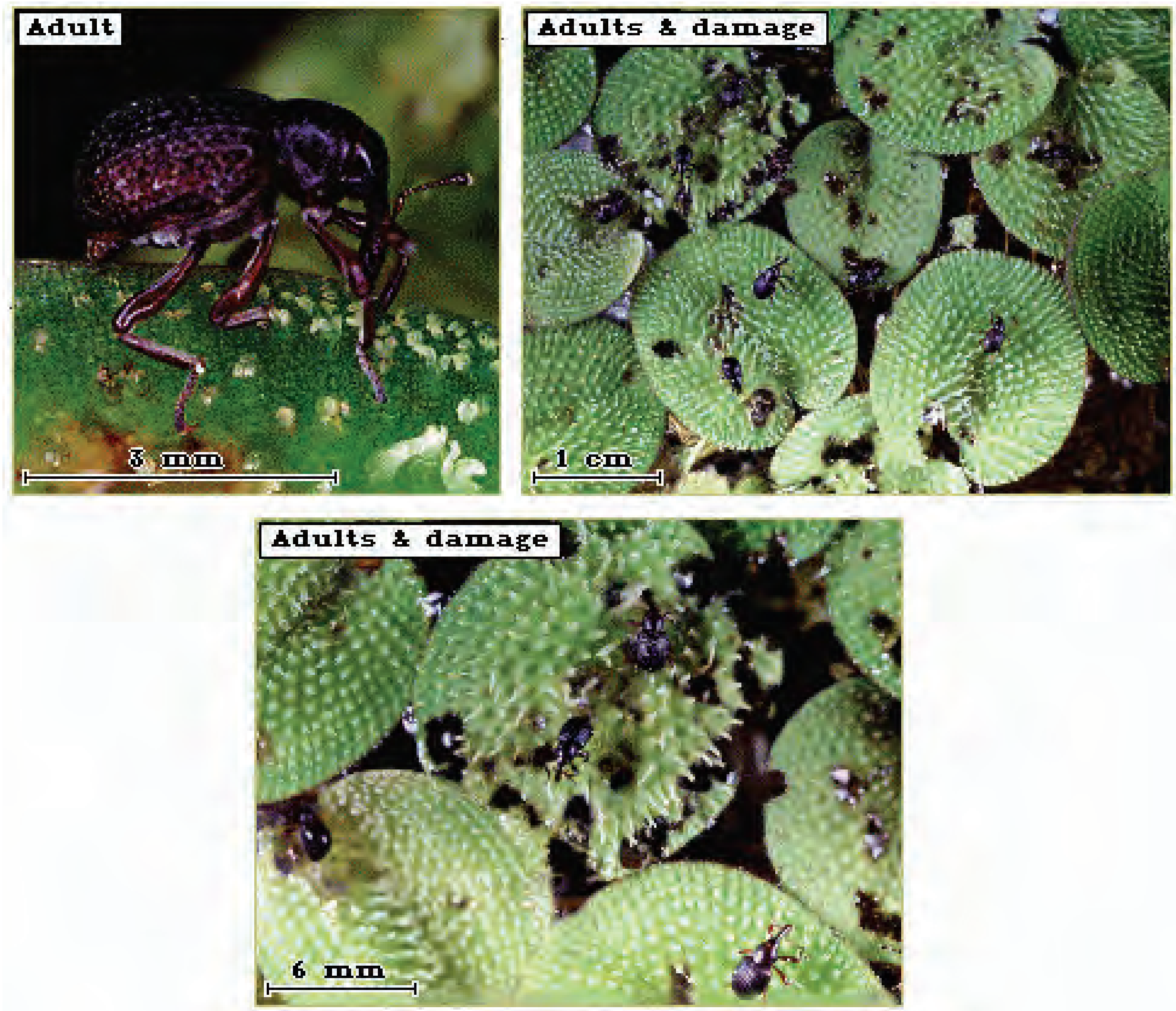

Figure 6. Salvinia weevil adults and damage.
(Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

The salvinia weevil (*Cyrtobagous salviniae* Calder and Sands) was first discovered in the United States at the Archbold Biological Station, Highlands County, Florida in 1962 (Center et al. 1999). Due to the lack of U.S. records, it was assumed that the weevils were accidentally introduced from South America. The salvinia weevil feeds on the nuisance, floating ferns, giant salvinia (*Salvinia molesta* D.S. Mitchell), and common salvinia (*S. minima* Baker), and has been used successfully as a biocontrol agent in India, Africa, Sri Lanka, Southeast Asia, Papau New Guinea, and Australia,

dramatically reducing large infestations of *Salvinia* (Center et al. 1999, Julien and Griffiths 1999).

Biology

Salvinia weevils are small and generally reside on the underside of *Salvinia* fronds (ERDC, 2005, APIS, Julien et al. 2002) (Figure 6 – Adult). The average size of the males is 1.8 x 0.9 mm, which is slightly smaller than the females (2.2 x 1.2 mm) (Julien et al. 2002). Newly emerged weevils are brown in color darkening to black after about five days (Julien et al. 2002). The females lay single eggs in the floating leaves of giant *Salvinia* (Center et al. 1999). Eggs hatch in about 10 days. The larvae are white and approximately 3 mm in length (Center et al. 1999). One important characteristic of *C. salviniae* that distinguishes it from another *Cyrtobagous* weevil, *C. singularis* Hustache, is its larval feeding habit. The larvae of *C. salviniae* tunnel into the rhizomes of *Salvinia* causing them to disintegrate, while the adults feed on the buds, suppressing plant growth (Center et al. 1999). The larvae and adults of *C. singularis* only feed on leaves and other tissues and not on the actively growing rhizomes or meristems, making it an ineffective biocontrol agent. Distinguishing between the two species is essential to insure successful biological control (Center et al. 1999).

Host-Specificity

In South America, Forno et al. (1983) observed *C. salviniae* (at that time thought to be *C. singularis*) attacking *Salvinia* spp. and not feeding on plants that grow in association with it (waterfern (*Azolla* spp.), waterhyacinth (*Eichhornia crassipes* [Mart.] Solms-Lauback), and waterlettuce (*Pistia stratiotes* L.)). This weevil was later found to be a new species and was subsequently described as *C. salviniae* Calder and Sands (Julien et al. 2002). In Australia host range tests were conducted with *C. salviniae* on 46 species of plants - six families of Pteridophyta (ferns), eleven families of Monocotyledons, and sixteen families of Dicotyledons (Forno et al. 1983). Adult feeding occurred on waterlettuce, but the insect could not reproduce on the plant. It also fed on sweet potato (*Ipomea batatas* (L.) Lam.) when this plant was held in contact with water, but when grown in its normal, non-aquatic situation, the weevils failed to feed on it. The conclusion of the host-specificity tests was that *C. salviniae* was restricted to feeding on *Salvinia* spp. Even when huge populations of weevils were starving once

the *Salvinia* spp. had crashed, they were not found attacking other plant species (Julien et al. 2002).

Research/Impact

The feeding action of both the adults (Figue 6 - Adults and damage) and larvae can have a devastating effect on field populations of *Salvinia* spp. Results of the feeding damage appear in months rather that in years, which is the usual action of other biocontrol agents (ERDC, 2005, APIS). The initial damage appears as a browning of the plants, which spreads out until almost the entire mat is brown and damaged. Once the damage is widespread and the plants are sufficiently damaged, the mat begins to sink (ERDC, 2005, APIS).

Possible Use in Control Programs

In 1999 *C. salviniae* collected from common salvinia in Florida by scientists from the USDA, ARS, Invasive Plant Research Laboratory were released at several sites in Texas and one site in Louisiana, but establishment was unsuccessful (Julien et al. 2002, ERDC, 2005, APIS).

Leeda A. Wood and Daniel Flores, both entomologists with the United States Department of Agriculture (USDA), Center for Plant Health Science and Technology, Plant Protection and Quarantine, Animal and Plant Health Inspection Service, Pest Detection, Diagnostics and Management Laboratory, 22675 N. Moorefield Rd., Moore Air Base Bldg. 6414, Edinburg, TX 78541-9398, are currently working on ways to develop biological control strategies for giant salvinia in East Texas using *C. salviniae*. They are documenting the distribution of giant salvinia and the extent of infestations in waterways in East Texas. In addition they are examining dispersal techniques for *C. salviniae*, evaluating previous field releases in East Texas, evaluating previously used methods for controlling giant salvinia in East Texas, documenting the impact of *C. salviniae* on nontarget species, and transferring this technology to other agencies for managing giant salvinia. These two USDA scientists have been in contact with personnel at the Lewisville Aquatic Ecosystem Research Facility (LAERF), in Lewisville, TX, a research facility that is part of ERDC, to help them develop mass-rearing techniques for *C. salviniae*.

In May 2004, four ponds of giant salvinia were set up at LAERF for a mass-rearing experiment of the salvinia weevil. The pond experiment

(Figure 7 – A, B, C, and D) was designed to examine the effects of fertilized giant salvinia on the establishment of *C. salviniae*: Pond A - fertilized every two weeks with 100 lb ammonium sulfate; Pond B - fertilized every two weeks with 40 lb ammonium sulfate; Pond C - fertilized every 2 weeks with 10 lb ammonium sulfate; and Pond D – not fertilized. According to LAERF personnel, the ponds with the higher nitrogen rate had more and larger brown areas of giant salvinia (i.e. more insect damage) (conversation with LAERF personnel, November 2004).

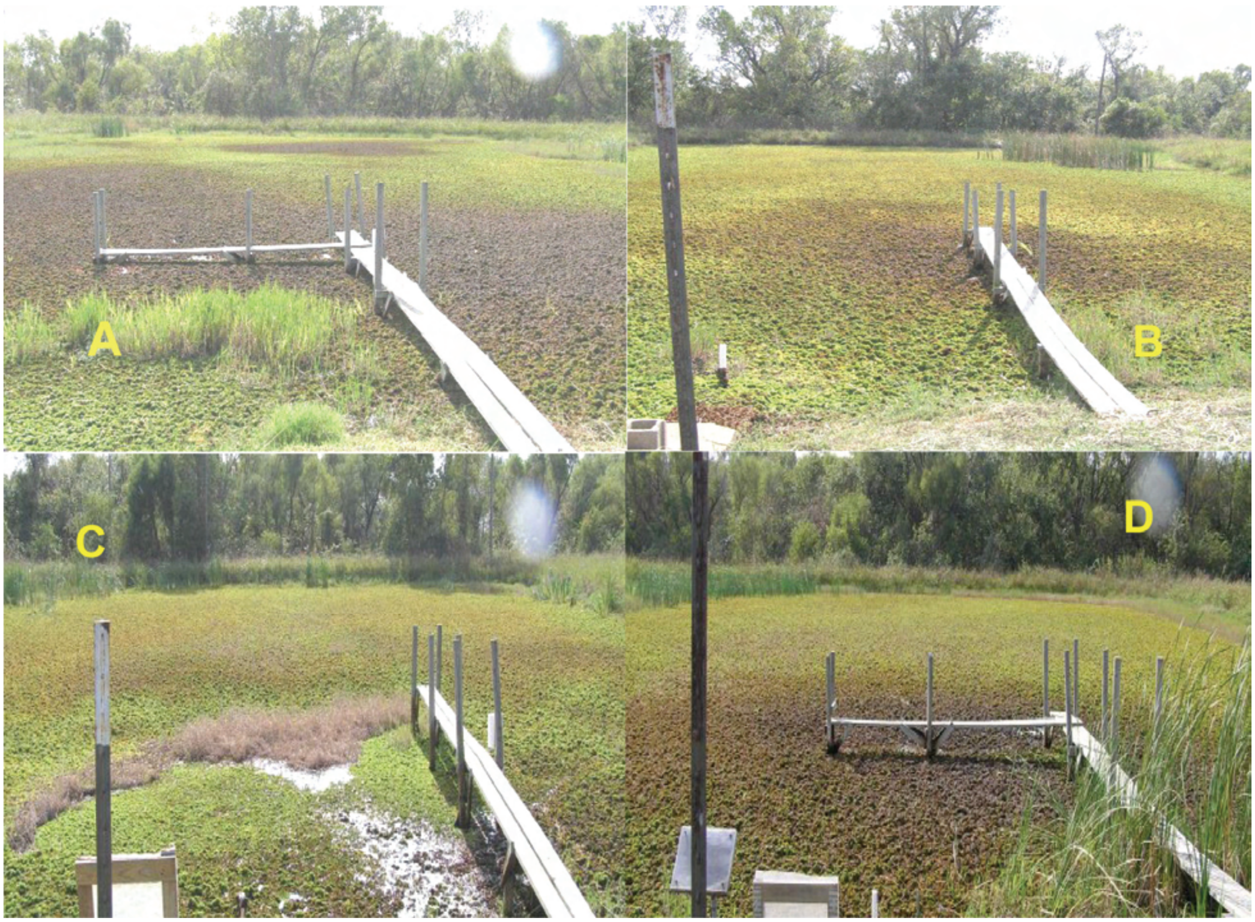

Figure 7. *C. salviniae* released in four ponds at LAERF - May 2004. Photograghs taken four months after release: (Pond A) 100 lb ammonium sulfate every 2 weeks, (Pond B) 40 lb ammonium sulfate every 2 weeks, (Pond C) 10 lb ammonium sulfate every 2 weeks, and (Pond D) not fertilized. (Photos courtesy of LAERF personnel.)

More efficient and less labor-intensive procedures are needed to mass-rear and release large numbers of the weevils. Also needed are better adult extraction methods so weevils can be released on both *S. molesta* and *S. minima* simultaneously. In addition, more efficient field evaluation methods are needed.

Donacia spp., Long-Horned Leaf Beetles (Coleoptera: Chrysomelidae: Donaciinae) (Figures 8 and 9)

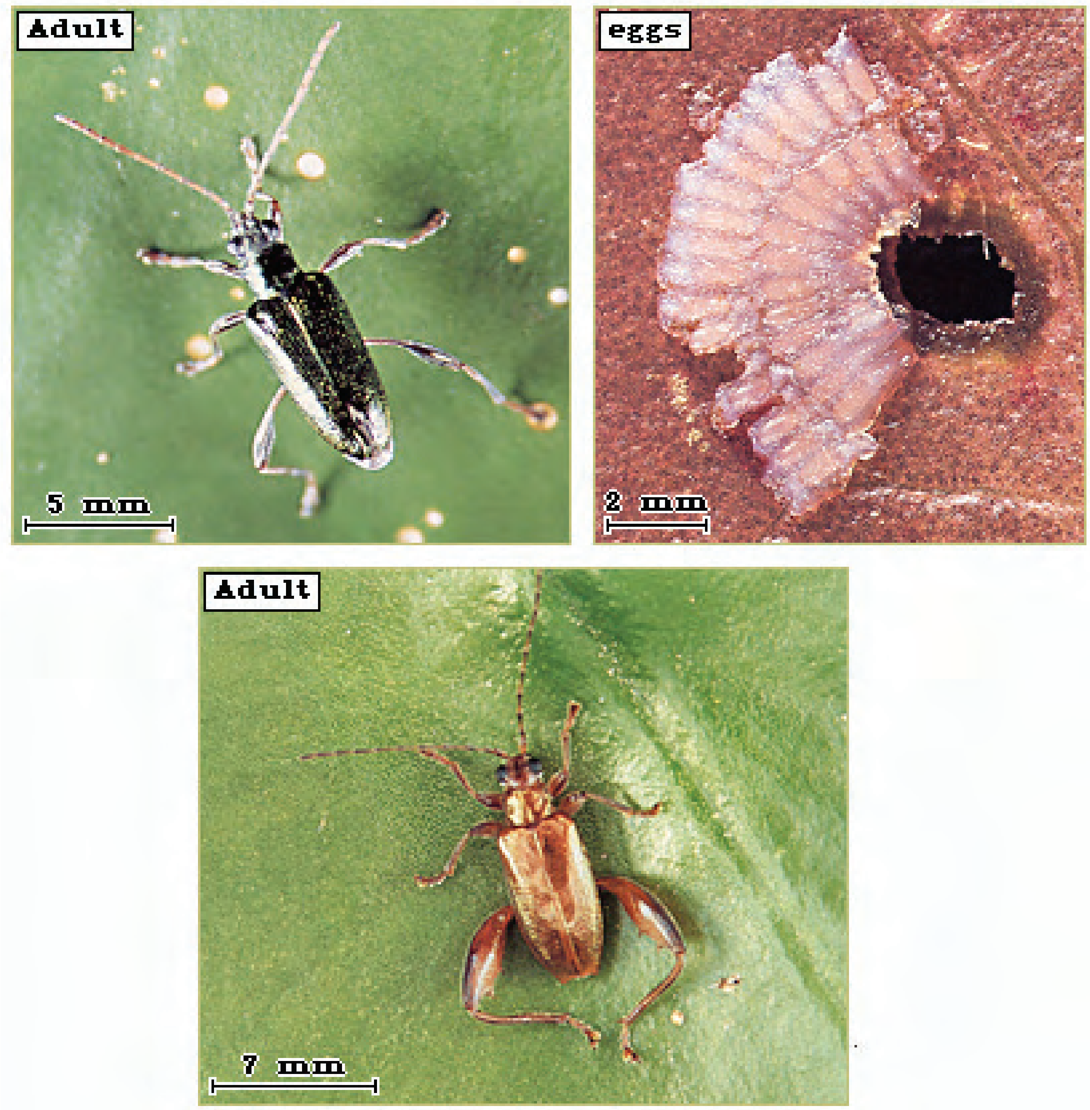

Figure 8. Eggs and adults of the long-horned leaf beetle. (Photographs courtesy of the ERDC, 2005, APIS.)

Figure 9. Long-horned leaf beetle larvae feeding on a stalk of American Lotus, Lake Cypress Springs, Texas - 2004. (Photographs courtesy of Dr. Michael J. Grodowitz, ERDC, and Julie G. Nachtrieb, LAERF.)

General Information and History

Donacia spp., the longhorned leaf beetles, belong to the largest group of aquatic Chrysomelids in North America (Center et al. 1999, ERDC, 2005, APIS). Despite being such a large group, few details are known about most of the species' life histories. Of the 31 *Donacia* species occurring in North America, most are found in the southeastern United States (Center et al. 1999).

Biology

Long-horned leaf beetles, as described by Borror et al. (1976), are seldom found far from water, and the adults are frequently located on the flowers

or foliage of water lilies, pondweed, and other aquatic plants (Figure 8 - Adults). Eggs are usually laid on the undersides of leaves of aquatic plants (Figure 8 - Eggs). The larvae feed on the submerged portions and obtain air through the plant stems (Figure 9). Pupation occurs in cocoons that are fastened to the submerged parts of the vegetation.

Host-Specificity

Long-horned leaf beetles feed on at least 50 aquatic plant species, including spatterdock (*Nuphar lutea* (L.) Sm.), waterlily (*Nymphaea* spp.), and American lotus (*Nelumbo lutea* (Willd.) Pers.) (ERDC, 2005, APIS). Unfortunately, very little species specific information is available.

Research/Impact

To date, no research has been conducted describing the impact of this insect on its host plants (Center et al. 1999), or its possible use in biocontrol programs. In 2004, Dr. Michael J. Grodowitz (ERDC) and Julie G. Nachtrieb (LAERF) found *Donacia* spp. larvae covering the stalks of American lotus in Lake Cypress Springs, Texas. The larvae had degraded the plants to such a degree that the lotus could be pulled straight out of the lake's sediment with little or no effort. Despite being native, American lotus can sometimes become a nuisance plant. Bassett et al. (1993) warn that American lotus can grow so rapidly it can completely cover a 1-acre pond in 3 to 4 years and should never be introduced into most fishing ponds. Whetstone et al. (2000), Cooperative Extension specialists at Clemson University, caution in their publication "Home and Garden Information Center: Aquatic Plant Selection" that American lotus may be invasive. From the voracious feeding of *Donacia* spp. larvae on American lotus at Lake Cypress Springs, this insect could be viewed as a potential biocontrol agent in situations where American lotus has become invasive.

Possible Use in Control Programs

More research is needed in describing various species taxonomically and developing information on life history, biology, host-specificity, and ecology. Once this information is obtained and individual species appear promising, mass-rearing techniques should be developed.

Euhrychiopsis lecontei (Dietz), Milfoil Weevil (Coleoptera: Curculionidae) (Figures 10 and 11)

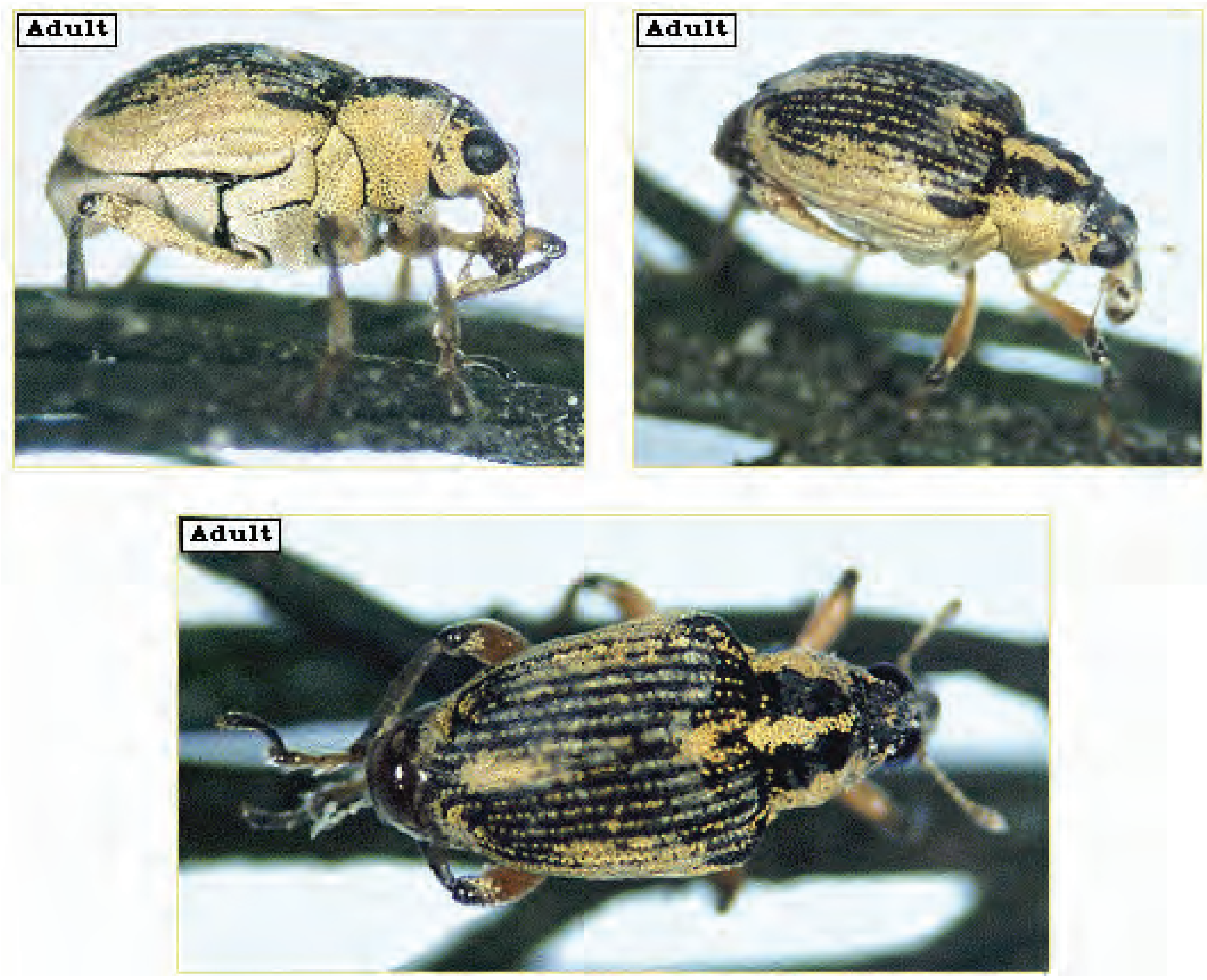

Figure 10. Milfoil weevil adults. (Photographs courtesy of the ERDC, 2005, APIS.)

Figure 11. Milfoil weevil larva in stem nearing pupation. (Photograph by Robert L. Johnson, Cornell University, www.forestryimages.org, www.invasive.org/search.)

General Information and History

The submersed aquatic milfoil weevil (*Euhrychiopsis lecontei* Dietz), is a native North American species that traditionally feeds on northern watermilfoil (*Myriophyllum sibiricum* Komarov) (Johnson and Blossey 2002; Solarz and Newman 2001). After a EWM decline in Browning Pond, Vermont was linked to *E. lecontei*, surveys and research were conducted to determine whether this native weevil would be a viable insect biocontrol agent for EWM (Creed and Sheldon 1994b).

Biology

The weevils are small (2 to 3 mm in length), dark in color with brown and yellow markings on the upper half of the body (Grodowitz et al. 2007, Johnson and Blossey 2002) (Figure 10 - Adults), and feed on leaves and stems. After mating, the females lay an average of 1.9 eggs per day, about 200 total, producing one egg per EWM apical meristem (Johnson and Blossey 2002). Adults and all larval stages of the milfoil weevil feed on EWM. First instar larvae burrow into the meristem feeding for 3 to 5 days whereas older larvae feed inside the stem causing extensive damage and holes (Figure 11) (ERDC, 2005, APIS). Adult weevils feed on the meristems, leaves, and stems of EWM. The result of adult and first instar larvae

feeding can have a significant effect on the plant's growth (Creed and Sheldon 1994b). The effect of later instar larvae feeding on the plants is more varied, but may influence EWM growth by destroying stem vascular tissue (Creed and Sheldon 1994b).

Host-Specificity

Host plants for *E. lecontei* include the exotic EWM and the native northern watermilfoil (Creed and Sheldon 1994a, Solarz and Newman 2001). The weevil oviposits and develops on both species of plant, but host plant preference was affected by which species of plant the weevils were collected or reared on. Weevils that were collected or reared on EWM preferred it, however insects collected or reared on northern watermilfoil, had an equal preference for both EWM and northern watermilfoil (Solarz and Newman 2001). In another experiment, weevil populations that had been exposed to both EWM and northern watermilfoil were used in a four-species oviposition experiment (Solarz and Newman 2001). The four watermilfoil species included two natives (northern milfoil and whorled watermilfoil (*M. verticillatum* L.) and two exotics (EWM and parrotfeather). From this experiment, both EWM and northern watermilfoil exposed weevils oviposited on all four watermilfoil species. The weevils exposed to EWM, however, had a higher preference for this plant while northern watermilfoil exposed weevils distributed their preferences fairly evenly for all four watermilfoil species (Solarz and Newman 2001).

The knowledge of hybridity between EWM and *M. sibiricum* has developed new questions about the effectiveness of *E. lecontei*, since hybrids often deter herbivory better than their parental species (Floate and Whitham 1994; Fritz et al. 1994; Whitham et al. 1999; Moody and Les 2002). A population of EWM growing in Lake Beulah, Wisconsin was considered to be resistant because it showed very little damage from the milfoil weevil, and no pupal development was seen on apical meristems (Jester et al. 2000). Upon examination and analysis of the plants, they were found to be hybrids, demonstrating that hybrid milfoils can show resistance to leaf-feeding weevils (Moody and Les 2002).

Research/Impact

Extensive research has been conducted on *E. lecontei* including: (1) developmental rates and damage to EWM at constant temperatures (Mazzei et al. 1999); (2) weevil-EWM interaction at different spatial scales (Creed

2000); (3) temporal and spatial changes in EWM distribution and biomass associated with weevils in Fish Lake, WI (Lillie 2000); and (4) the relationship between water quality, watermilfoil frequency, and weevil distribution in the state of Washington (Tamayo et al. 2000). Creed and Sheldon (1994b) also conducted extensive studies to determine the effect *E. lecontei* had on EWM in pool and aquarium experiments.

Creed and Sheldon (1994b) determined that *E. lecontei* adults and first instar larvae could have a significant negative effect on EWM growth. Adults and first instar larvae feeding on milfoil meristems slowed the increase in plant length by preventing further apical growth. Adults feeding on leaves removed significant amounts of whole leaves and leaflets, severely affecting the energy balance of the plant. Herbivory on upper leaves also forced the plant to rely on deeper leaves for photosynthesis. Lesions created by adult feeding made the plants more susceptible to bacterial and fungal attacks. The combination of stem feeding by both adults and larvae caused the plants to lose buoyancy and eventually to sink.

Late instar larvae of *E. lecontei* influenced EWM growth by destroying stem vascular tissue (Creed and Sheldon 1994b). Removal of vascular tissue could reduce or halt the translocation of nutrients and sugars within the plants.

Possible Use in Control Programs

According to Creed and Sheldon (1994b), *E. lecontei* meets the criteria outlined by Harley and Forno (1992) for a successful classical biocontrol agent. Specifically it: (a) becomes a permanent part of the biota; (b) is self-regulating and self-perpetuating; and (c) provides acceptable control of the target plant, in this case, EWM. *Euhrychiopsis lecontei* is already a permanent member of the North American biota; survey data taken by Creed and Sheldon (1994b) at Brownington Pond, a 54-ha pond in northeastern Vermont, between 1986 and 1989, showed that the weevil is self-perpetuating and self-regulating. Brownington Pond originally had EWM beds covering 30 to 35 percent (10 - 11 ha) of the littoral zone. By 1989, only ca. 1.0 percent of the littoral zone was covered by EWM. Creed and Sheldon (1994b) both felt that, based on the results and observations of their studies, *E. lecontei* should be considered for use as a biological control agent for EWM in North America. More efficient mass-rearing and release strategies, coupled with additional information on field impact, is needed, however.

Hydrilla Leaf-mining Flies, *Hydrellia bilobifera* Cresson, and *H. discursa* Deonier (Diptera: Ephydridae: Notiphilinae: Hydrelliini) (Figures 12-15)

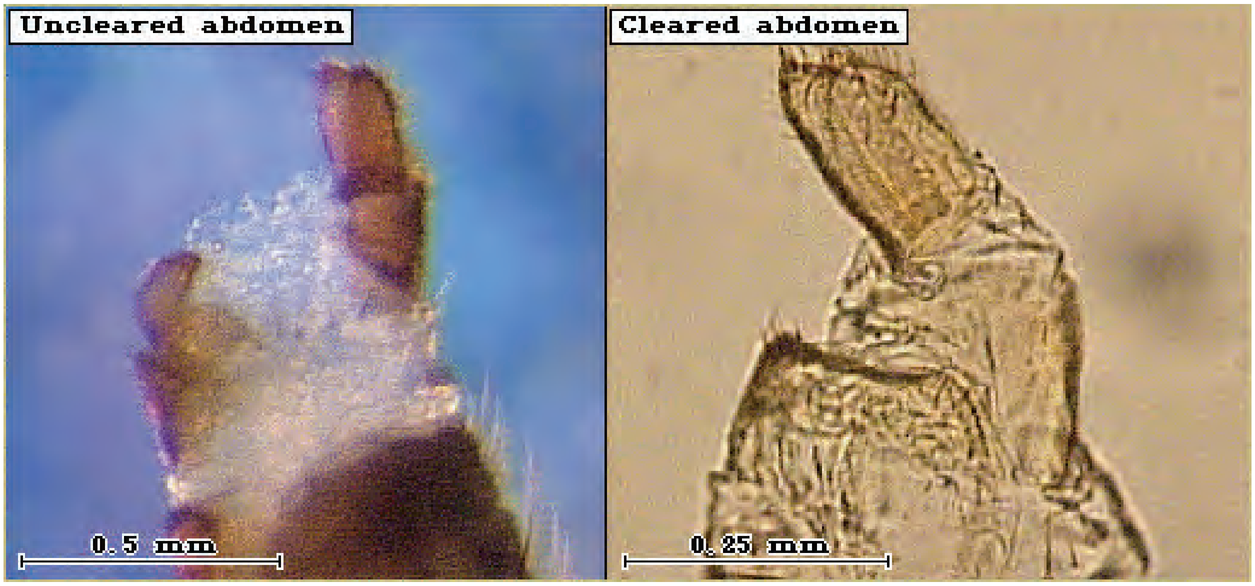

Figure 12. Female – *Hydrellia bilobifera* – cerci are long and narrow. (Photographs courtesy of the ERDC, 2005, APIS.)

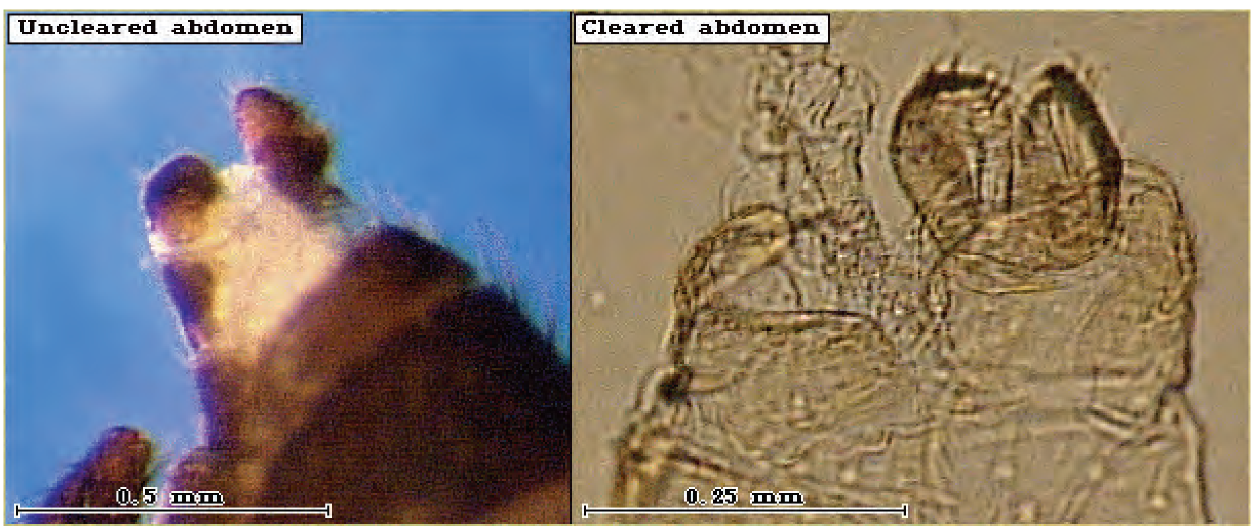

Figure 13. Female – *Hydrellia discursa* - cerci are short and round. (Photographs courtesy of the ERDC, 2005, APIS.)

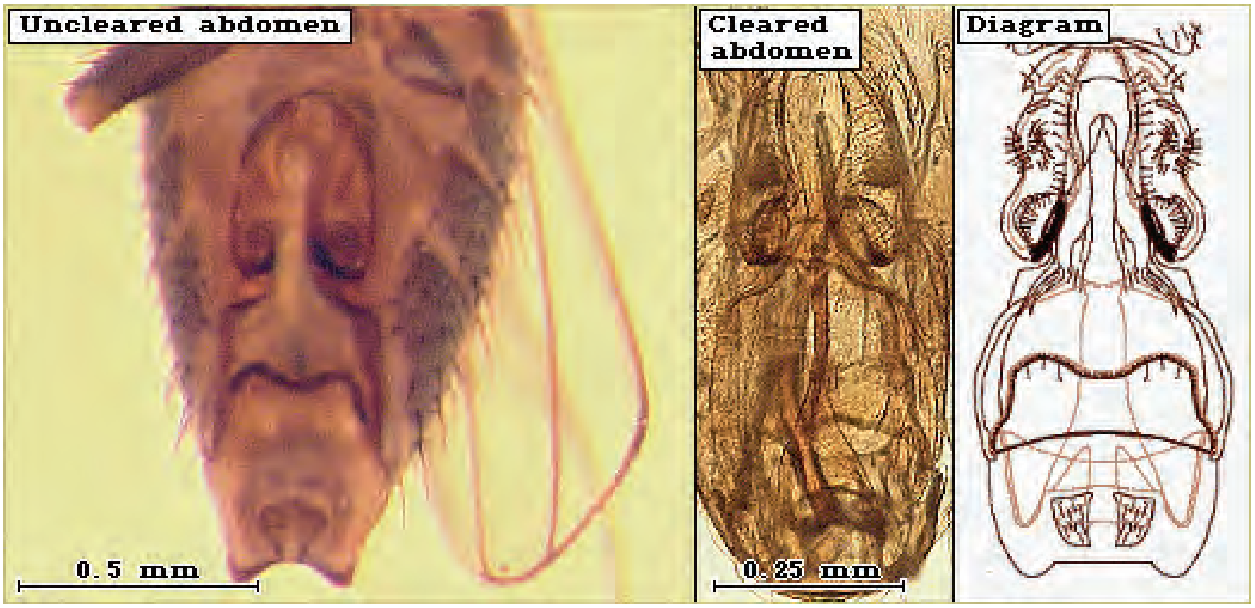

Figure 14. Male – *Hydrellia bilobifera* – prominent lobes at the base of the abdomen. (Photographs courtesy of the ERDC, 2005, APIS.)

Figure 15. Male – *Hydrellia discursa* – no lobes at the base of the abdomen. (Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

The family Ephydridae is a large group of insects with ca. 350 North American species including the genus *Hydrellia* (Borror et al.1976). There are over 50 species of *Hydrellia* in North America and two of these, *H. bilobifera* and *H. discursa*, have been found in association with the submersed, nuisance aquatic plant, hydrilla (ERDC, 2005, APIS), as well as

other potentially nuisance native plant species, including several species of pond weeds (Deonier 1971).

Biology

Hydrellia bilobifera and *H. discursa* look very similar to *H. pakistanae* and *H. balciunasi,* two species of leaf-mining flies that have been introduced as insect biocontrol agents of hydrilla. The primary way to distinguish between the flies is to examine their genitalia (ERDC, 2005, APIS). In female *Hydrellia*, the cerci are distinctive. In *H. bilobifera* they are long and narrow (Figure 12), and in *H. discursa*, they are short and round (Figure 13). Abdomens are one of the key features to distinguishing between male *Hydrellia*. The abdomens of the two introduced species are about the same length as their thorax, whereas the native species abdomens' are 1.5 – 2.0 times longer than their thorax (Center et al. 1999, ERDC, 2005, APIS). To distinguish between the two native males, distinctive lobes are found at the base of the abdomen in *H. bilobifera* (Figure 14), but are absent from *H. discursa* (Figure 15) (Center et al. 1999). Another distinguishing characteristic between the native and introduced *Hydrellia* is that the adult *H. bilobifera* and *H. discursa* are generally larger (1.6-2.3 mm long) than the introduced flies, *H. pakistanae* and *H. balciunasi* (which are only 1-2 mm long) (Center et al. 1999).

Host-Specificity

The host plants of *H. bilobifera* include four species of pondweed (*Potamogeton* spp.) and horned pondweed (*Zannichellia palustris* L.), while the primary host plant of *H. discursa* is grass-leaved pondweed (*P. gramineus* L.) (ERDC, 2005, APIS). Hydrilla is also considered a host plant, and the larvae of both *H. bilobifera* and *H. discursa* feed on the leaves and stems of hydrilla (Center et al. 1999). Several generations of these two insect species can be reared on hydrilla (ERDC, 2005, APIS).

Research/Impact

The primary research that has been accomplished on these insects is to establish important genitalia characteristics to be able to distinguish them from the two introduced species as well as other native *Hydrellia* (Deonier 1971, ERDC, 2005, APIS). Also as mentioned earlier, several generations of *H. bilobifera* and *H. discursa* were reared successfully using only hydrilla.

Both native *Hydrellia* are often found in association with hydrilla but only *H. bilobifera* is known to feed and develop on hydrilla (ERDC, 2005, APIS). The larval stage of *H. bilobifera* lasts 14 to 31 days in which time it damages ca. twenty hydrilla leaves (Center et al. 1999). Because *H. discursa* is often found on hydrilla, it is assumed that they feed on hydrilla. It is not certain, however, if *H. discursa* feeds and develops on hydrilla (ERDC, 2005, APIS).

Possible Use in Control Programs

Since *H. bilobifera* (and assuming *H. discursa*) feed on hydrilla causing damage to the leaves and stems, they should be considered for use in hydrilla biocontrol programs, possibly to supplement populations of the two introduced species. As they are native and have been found in association with hydrilla infestations and have been reared successfully on hydrilla (ERDC, 2005, APIS), mass-rearing these insects might be beneficial to aid biocontrol programs in the management of hydrilla. In addition, more information is needed to determine if these species could be used to manage nuisance populations of several species of native aquatic plants.

Mycoleptodiscus terrestris (Gerd.) Ostazeski Fungi, Ascomycota, Ascomycetes, Sordariomycetidae, Incertae sedis, Magnaporthaceae (Figures 16-18)

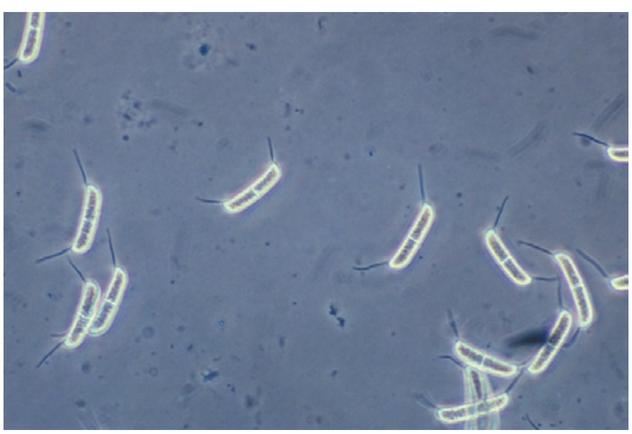

Figure 16. MT spores. (Photograph courtesy of Dr. Judy Shearer.)

Figure 17. MT on plate. (Photograph courtesy of Dr. Judy Shearer.)

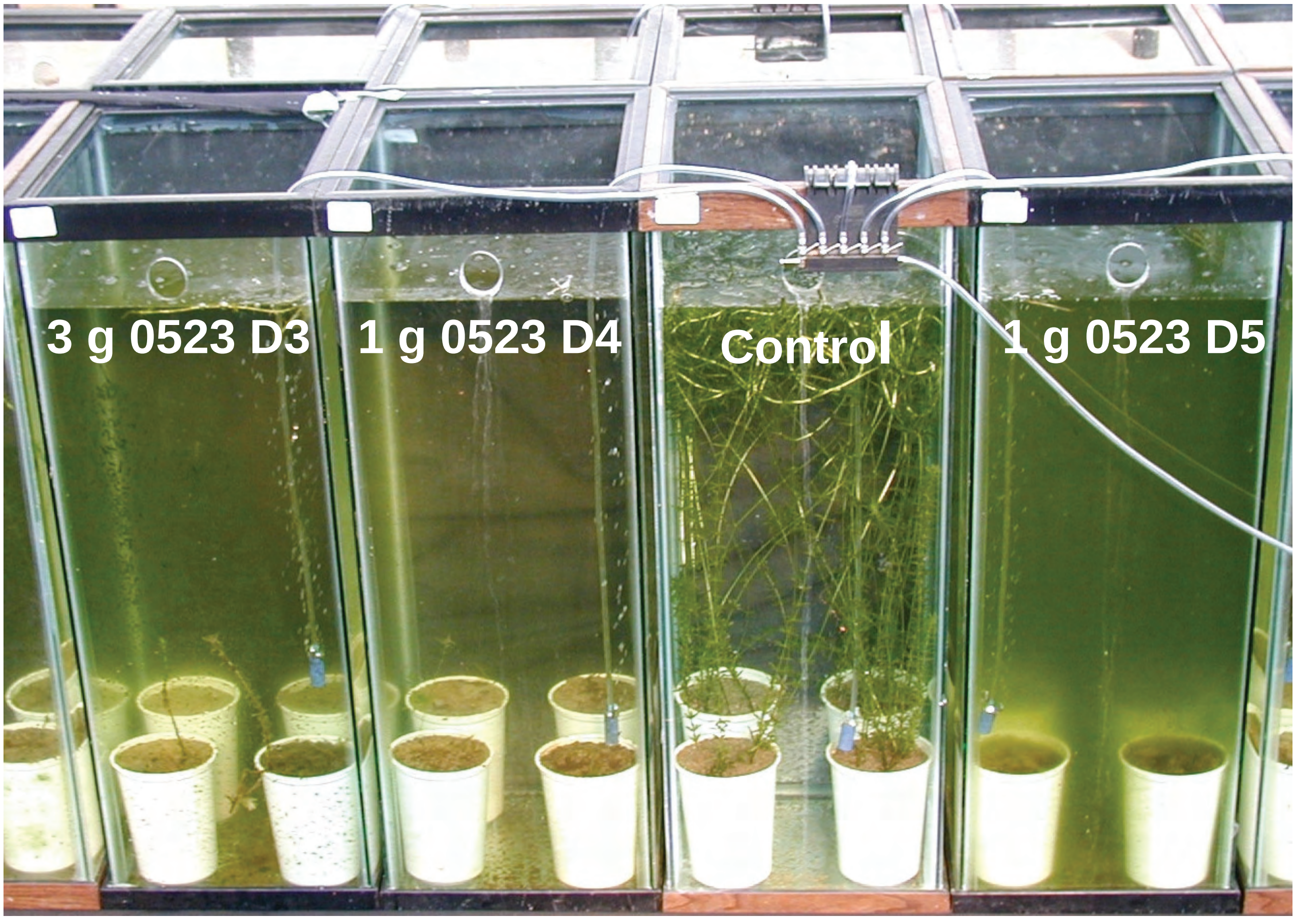

Figure 18. Mt aquaria study on hydrilla – the legend tells the amount of dry pathogen used (g), the experiment it came from (523), and the number of days the fermentation ran before harvesting (D). (Photograph courtesy of Dr. Judy Shearer.)

General Information and History

In the fall of 1987 and 1988, surveys were conducted in 15 lakes and 3 rivers in the southeastern U.S. to test for the presence of pathogens of hydrilla (Joye and Cofrancesco 1991). About 200 fungal and 27 bacterial isolates were collected, and a promising candidate was isolated from hydrilla foliage growing in Lake Houston, Texas (Joye 1988, 1989, 1990). Originally identified to be the indigenous fungal pathogen *Macrophomina phaseolina* (Tassi) Goid. (Joye 1990), it was later discovered to be *Mycoleptodiscus terrestris* (Gerd.) Ostazeski, Mt (Shearer 1996a). Dr. Bruce Sutton, a world authority on Coelomycetes, at the International Commonwealth Institute, England, verified the identification of Mt (Shearer 1996a).

Isolations of Mt were also made from EWM collections from Massachusetts and Alabama in the late 1970s (Gunner 1983, personal communica-

tion Dr. Judy Shearer, 2005). It was considered to be a promising biocontrol candidate for EWM and early greenhouse and laboratory studies showed that Mt reduced milfoil biomass (Gunter et al. 1990, Stack 1990, Smith and Winfield 1991). Mt was developed into a mycoherbicide, Aqua-Fyte®, by EcoScience Corporation, Worcester, MA. Work conducted by Shearer (1994), showed that Aqua-Fyte® was ineffective in reducing the biomass of EWM under natural field conditions. Shearer (1996b) also demonstrated that while the pathogen Mt was very effective in greenhouse tests on EWM, field trials exhibited inconsistent results.

Biology

Mt is a dematiaceous fungus that reproduces asexually by hyaline two-celled spores (Figure 16) or by melanized survival structures called microsclerotia. No sexual stage is known. The spores arise from phialides that aggregate to form a one cell thick structure called a sporodochium. On standard laboratory media (Figure 17), the fungus does not produce spores but readily produces microsclerotia. Applied as a fungal suspension of hyphae and microsclerotia, Joye and Paul (1992) observed that the fungus is capable of attaching to hydrilla tissues in less than 24 hours and within 40 hours penetration through the cell wall is complete. Within 196 hours, complete colonization of hydrilla tissue was observed. Associated with fungal colonization was loss of cellular integrity followed by total plant collapse (Figure 18).

Host-Specificity

Host-specificity tests conducted by Joye and Cofrancesco (1991) showed that the fungal plant pathogen was nonpathogenic to 44 of 46 species and subspecific taxa within 22 families. They found that only hydrilla and duck lettuce (*Otellia alismoides* (L.) Pers.) were susceptible.

Research/Impact

Applied as a fungal suspension at rates of 0.2 ml L^{-1}, hydrilla shoot biomass reductions of 99-100 percent have been achieved in greenhouse trials. In more recent studies using 0.04 g L^{-1} of dried Mt, similar reductions have been recorded.

Mt was proven by both Joye (1990) and Shearer (1996a) to be a potential biocontrol agent of hydrilla. Field and greenhouse studies conducted by

both scientists showed that Mt significantly reduced hydrilla biomass after inoculation compared with untreated plants. Disease symptoms appeared in 5 to 7 days, and within 10 to 14 days, plants started to disintegrate. Other research being conducted by Drs. Judy Shearer and Linda Nelson (ERDC, Vicksburg, MS) integrates Mt with the herbicides fluoridone, endothall, and 2,4-D (Nelson et al. 1998, Nelson and Shearer 2002, Shearer and Nelson 2002, Nelson and Shearer 2005) to observe whether there is improved activity with the combination of pathogen and herbicide for aquatic plant management as opposed to using either method independently. Earlier work done by Netherland and Shearer (1996), demonstrated a potential for combining the two technologies, chemical and biological control, for the management of hydrilla.

Possible Use in Control Programs

Currently, Mt is being evaluated as a potential bioherbicide for hydrilla management (Balciunas et al. 2002). An Mt isolate collected on hydrilla in Texas (at a site different than Lake Houston) has proven to be the most successful of all isolates collected both in the U.S. and overseas (August 2004, personal communication, Dr. Judy Shearer). This isolate is deposited in the culture collection at the United States Department of Agriculture, Agriculture Research Service, National Center for Agricultural Utilization Research (USDA, ARS, NCAUR) in Peoria, IL. The accession number for this isolate is NRRL Number 30559. Dr. Judy Shearer and Dr. Mark Jackson, USDA, ARS, NCAUR, Peoria, IL, are studying fermentation methods that will yield high concentrations of effective Mt propagules at a low cost. They have received a U.S. patent for the procedures. It is hoped that a bioherbicide can be produced that will be as effective and can be used alone or in an integrated approach with chemical herbicides.

Ostrinia penitalis (Grote), American Lotus Borer (Lepidoptera: Pyralidae: Pyraustinae) (Figure 19)

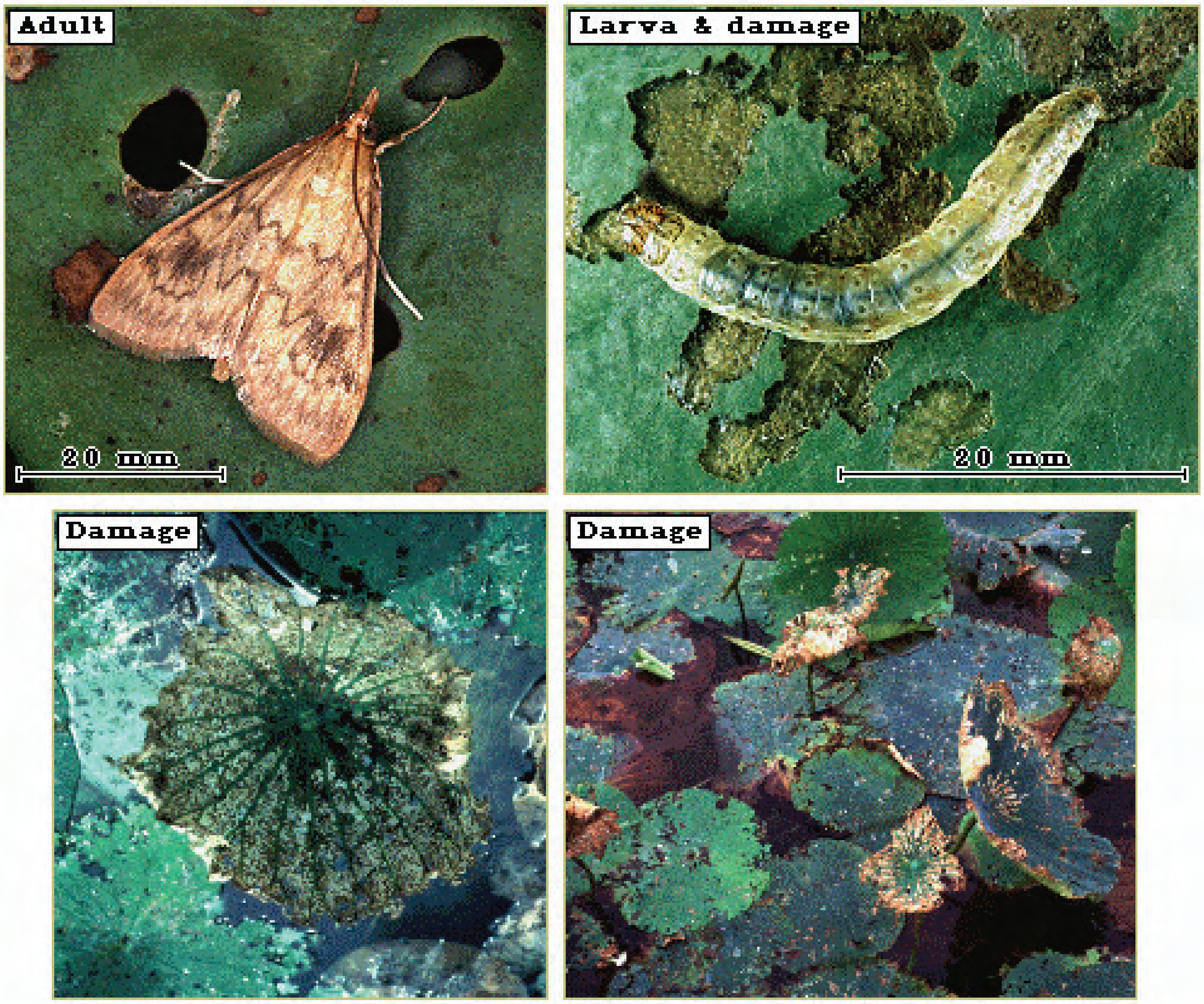

Figure 19. American lotus borer, adult, larvae, and larval damage.
(Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

The subfamily Pyraustinae is a large group of insects comprising over 300 North American species. Many of its members are relatively large and conspicuously marked (Borror et al. 1976). The most important species in this subfamily is the European corn borer (*Ostrinia nubilalis* (Hubner)). Closely related to the European corn borer is the American lotus borer (*O. penitalis* (Grote)). The American lotus borer is generally found in association with its preferred host plant, American lotus, but it also feeds on various species of smartweeds (*Polygonum* spp.) (Center et al. 1999).

Biology

Adult American lotus borers are medium-sized moths that are yellowish to orange in color (Figure 19 - Adult) (ERDC, 2005, APIS). Females lay their eggs in groups of about 60 on the upper surface of lotus leaves (Center et al. 1999). The larvae feed on the outer edges of leaves staying attached by a series of fine silken strands that keep them from being swept away by wind or wave action (Figure 19 - Larva and damage) (ERDC, 2005, APIS). When the larvae feed near the leaf edges, they frequently roll an entire portion of the leaf around themselves (ERDC, 2005, APIS). Once the larvae mature, they stop feeding and burrow into the leaf petiole to pupate. Once pupation is completed, the adults emerge from previously formed exit holes (ERDC, 2005, APIS).

Host-Specificity

The primary host of the American lotus borer is American lotus, but they also feed on many species of smartweeds and knotweeds (*Polygonum* spp.) including denseflower knotweed (*P. densiflorum* Meisn.), marshpepper knotweed (*P. hydropiper* L.), and dotted smartweed (*P. punctatum* Ell.) (ERDC, 2005, APIS).

Research/Impact

Ostrinia penitalis can cause devastating damage to lotus beds where the extensive feeding can reduce the leaves to mere skeletons (ERDC, 2005, APIS). Emergent seed heads are often attacked by larvae, which consume the immature seeds (Center et al. 1999).

Possible Use in Control Programs

Ostrinia penitalis is a serious herbivore of American lotus since a single larva can cause leaf deterioration as well as attack the buds and seed-capsules (Welch 1919). Depending on the number of larvae present on a plant, the leaves will show signs of deterioration and loss of chlorophyll tissue will ensue (Welch 1919). When the larvae reach a certain size (ca. 14 mm), they begin to burrow into the plant. The burrow construction eventually severs the leaf connection from the rootstock and results in the ultimate destruction of the floating part of the American lotus (Welch 1919). More information is needed on life history, host-specificity, seasonal dynamics, and mass-rearing procedures before their use can be ascertained.

Parapoynx diminutalis Snellen, Asian Hydrilla Moth, (Lepidoptera: Pyralidae: Nymphulinae: Nymphulini) (Figure 20)

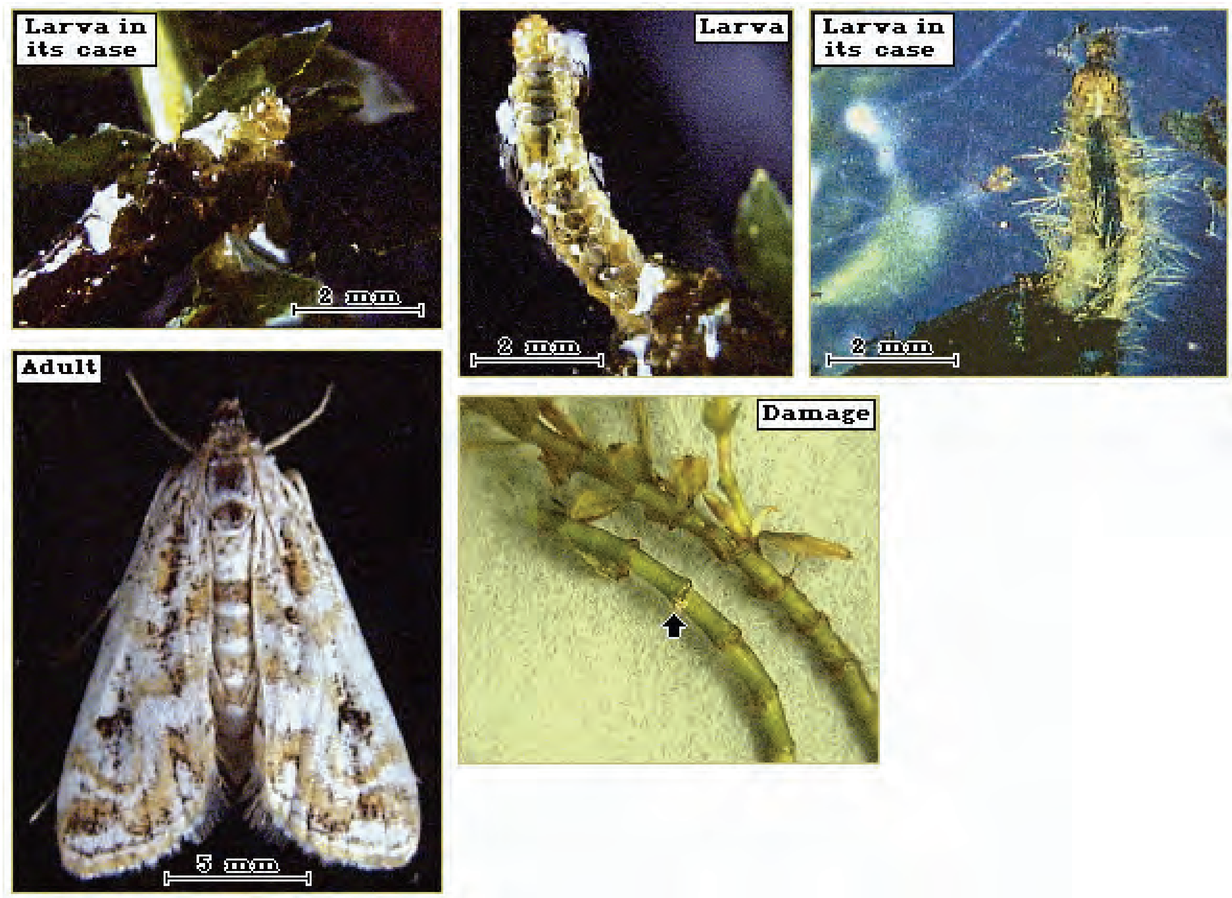

Figure 20. The Asian hydrilla moth larvae, adult, and damage to hydrilla. (Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

Center et al. (2002) describe the subfamily Nymphulinae as a group of moths that are almost all aquatic, with 18 species occurring in Florida. The Asian hydrilla moth (*Parapoynx diminutalis* Snellen), known from Pakistan to Southeast Asia (Delfosse et al. 1976), was first reported in Florida in 1976 feeding on hydrilla (Balciunas and Habeck 1981, Balciunas et al. 2002). It was probably brought into the state through the aquarium industry (Balciunas et al. 2002).

Biology

The female Asian hydrilla moth (Figure 20 - Adult) lays eggs in masses of about 30, placed on hydrilla leaves and stems that are exposed at the surface of the water (Center et al. 2002). Eggs hatch in about 4 to 6 days and

larval development takes 21 to 35 days, depending on the temperature. Young larvae feed by scraping the leaf surface or by notching the leaf margin (Figure 20 - Larva and damage). First and second instars sometimes feed within a simple case made by attaching a small piece of leaf wrapped over them. Later instars make tubular cases from stems or leaves that attach to one another with silk (Figure 20 - Larva in its case). Pupae are enclosed in an air-filled white silken cocoon attached to one side of the submersed hydrilla stem (Buckingham and Bennett 1996).

Host-Specificity

Laboratory tests conducted by Buckingham and Bennett (1989) found that the larvae of the Asian hydrilla moth developed on 14 plant species in13 genera. Larvae also developed on three combinations of species: (1) waterlily (*Nymphaea* spp.) and fragrant waterlily (*N. odorata* Ait.); (2) naid (*Najas minor* All) and southern naid (*N. guadalupensis* (Spreng.) Magnus); and (3) horned pondweed (*Zannichellia pulstris* L.) and needle spikerush (*Eleocharis acicularis* (L.) Roemer and Schultes). Hydrilla was usually the preferred host by larvae when paired with a test plant, but it was not the preferred host by ovipositing females in small-cage tests. These tests indicated that the following plants might be at risk for larval attack in the field: fanwort (*Cabomba caroliniana* A. Gray), coontail (*Ceratophyllum demersum* L.), egeria (*Egeria densa* Planch.), southern naiad, and EWM.

Research/Impact

Further testing by Buckingham and Bennett (1996) found that *P. diminutalis* larvae could be very damaging to hydrilla planted in pools or other protected containers in Florida. Larvae were also found frequently on other plant species associated with hydrilla in their research plantings. In addition to hydrilla, they found immatures in the field on coontail (1 larva, 1 pupa), southern naiad (2 larvae), and Illionois pondweed (*Potamogeton illinoensis* Morong) (5 larvae, 3 pupae). This contrasted sharply with the 14 plant species in 13 genera that produced adults in their initial host range tests (Buckingham and Bennett 1989). The highest percentage of adults (90 percent) was produced on one replicate of fanwort, but the highest average percentage (48%) was on hydrilla (Buckingham and Bennett 1989).

Parapoynx diminutalis is well established in both Panama and Florida, but Buckingham and Bennett (1996) feel it would have a greater impact on hydrilla in Panama due to the milder climate. They found that in north-central Florida near Gainesville, larval populations were reduced to very low levels in the late winter and early spring. These populations rebounded quickly during some years, however, so that by late summer hydrilla stems near the surface had been extensively defoliated.

Possible Use in Control Programs

Parapoynx diminutalis was once considered as a potential biological control because it severely damages hydrilla growing in culture (Center et al. 1999). The moths only occur sporadically, however, and produce only minimal damage to hydrilla in the field (Center et al. 1999). From the research conducted by Buckingham and Bennett (1996), *P. diminutalis* would be useful in an integrated hydrilla control program. If augmentation of the moth populations were made in early summer, this might allow the populations to build up fast enough to slow the growth of hydrilla. This coupled with the use of herbicides or pathogens would cause the plants to decline more readily. However, the wide host range may preclude their use.

Perigaster cretura (Herbst), Primrose Leaf Weevil (Coleoptera: Curculionidae: Curculioninae: Ceutohynchini) (Figure 21)

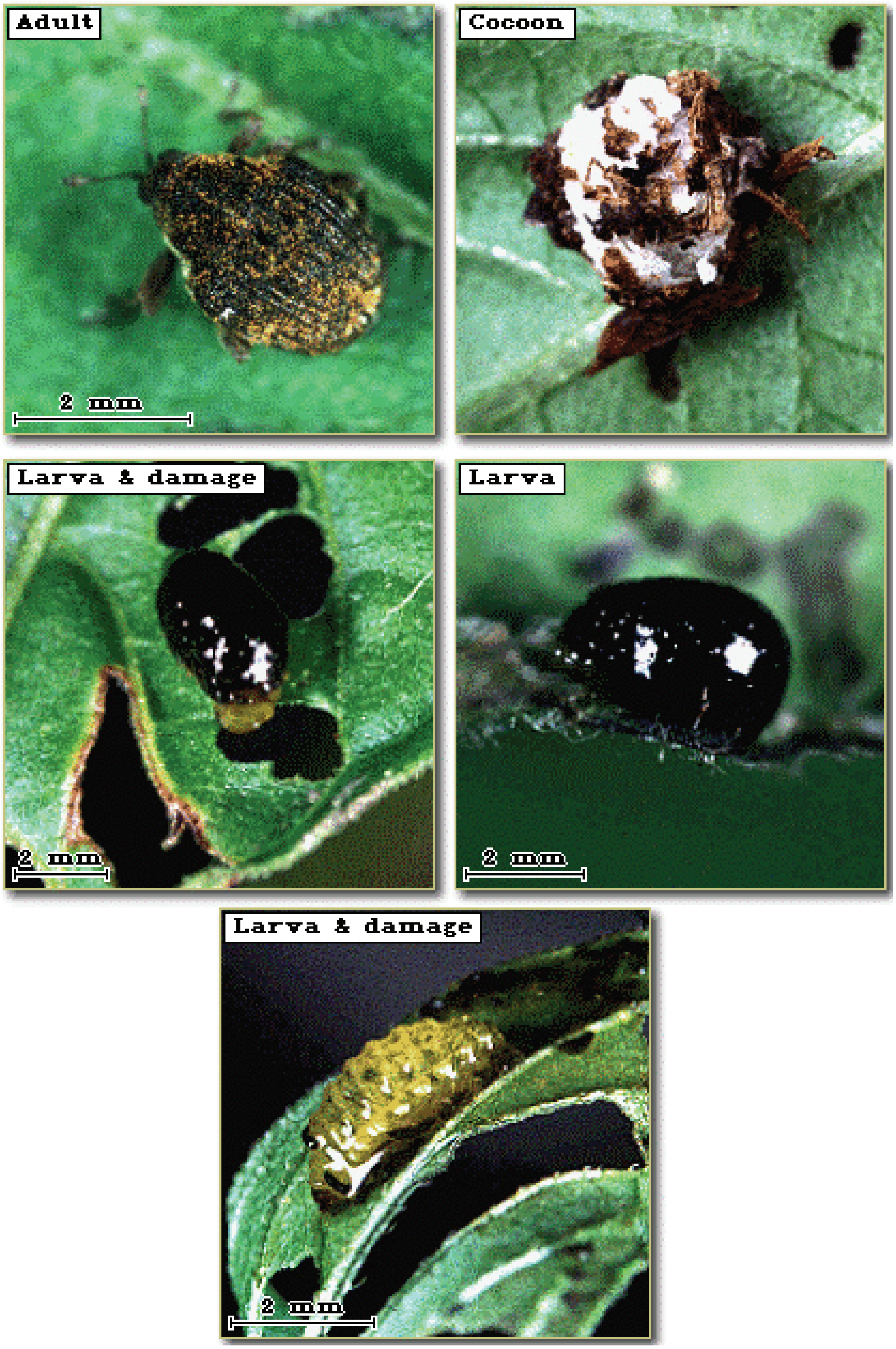

Figure 21. Primrose leaf weevil adult, cocoon, larva, and larval damage. (Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

The genus *Perigaster* consists of five species. Four species, including *P. cretura* (Herbst), occur in the eastern U.S.; the fifth species is found only in Panama (Clark 1976). *Perigaster cretura* feeds on species of water-primrose (*Ludwigia* spp.) (Clark 1976). The weevils are small (<3 mm) and feed during the day generally on the upper leaf surfaces of their host plants (Center et al. 1999, ERDC, 2005, APIS). When disturbed, the adults can jump, readily taking flight (Center et al. 1999). They are also able to create a creaking sound by rubbing ridged surfaces of their body together (Center et al. 1999).

Biology

Primrose leaf weevils are roundish in outline, brown to reddish brown in color with mottling of black and white (Figure 21 - Adult) (Center et al. 1999, ERDC, 2005, APIS). When handled, they tuck their snout and legs against their body "playing dead" (ERDC, 2005, APIS). The larvae develop through three instar phases, covering themselves with a protective layer of their own excrement (Clark 1976). Pupation occurs in a cell formed from a secreted material, excrement, and bits of debris (Figure 21 - Cocoon) (Clark 1976). When the adult emerges, it chews a hole through the upper portion of the pupal cell (Center et al. 1999, ERDC, 2005, APIS).

Host-Specificity

Plant hosts of the primrose leaf weevil include Mexican primrose-willow (*Ludwigia octovalvis*), floating primrose-willow (*L. peploides*), creeping primrose-willow (*L. repens*), and seedbox (*L. alternifolia*) (Center et al. 1999, ERDC, 2005, APIS).

Research/Impact

Both the larvae and adult feed on the leaves of water-primrose, creating numerous small holes throughout the leaves (ERDC, 2005, APIS). Larval feeding activity is especially extensive as they develop through their three instar phases (Figure 21 - Larva and damage) (Center et al. 1999).

Possible Use in Control Programs

Ludwigia spp., although native to North and South America, is considered to be a nuisance plant in most of its range (Balsbaugh and Hays 1972;

Aurand 1982, Chester and Hold 1990, McGregor et al. 1996). Since the plant hosts of *P. cretura* include four species of *Ludwigia*, this insect should be considered and studied as a potential candidate for water-primrose management.

Simyra henrici (Grote), Cattail Caterpillar (Lepidoptera: Noctuidae: Acronictinae) (Figure 22)

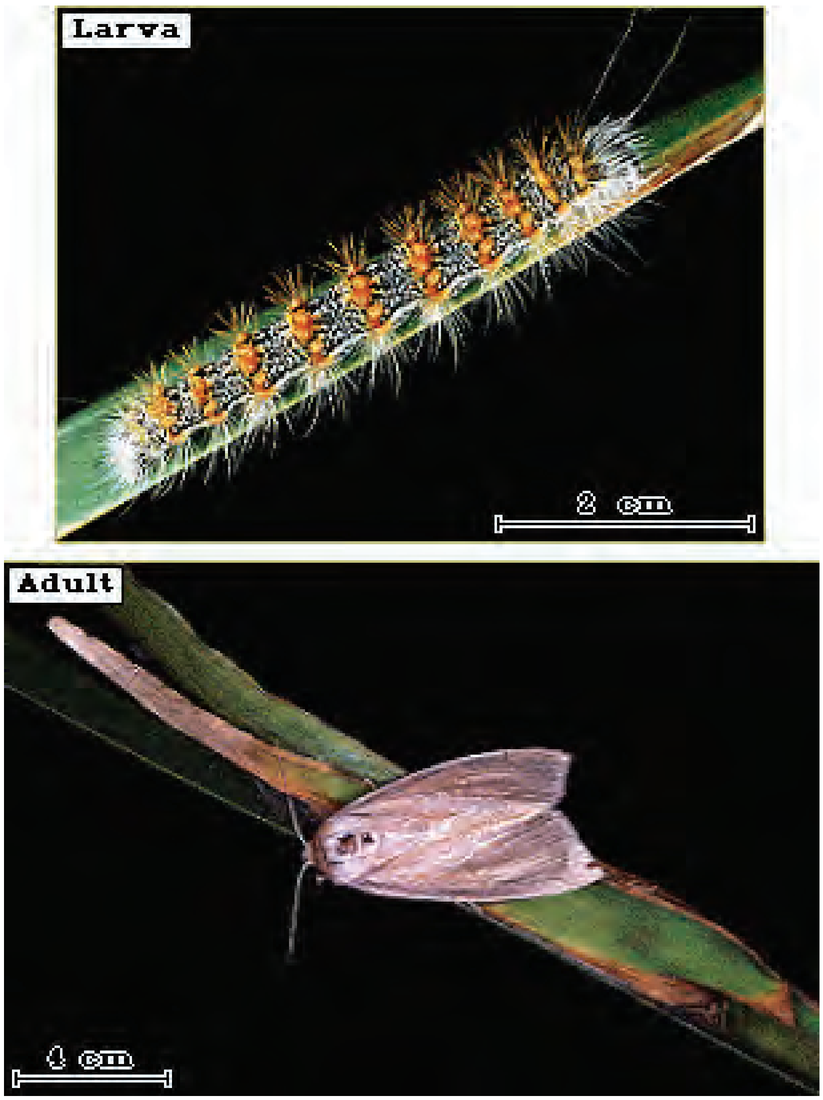

Figure 22. Cattail caterpillar larva and adult.
(Photographs courtesy of the ERDC, 2005, APIS.)

General Information and History

The cattail caterpillar (*Simyra henrici*) is widespread and commonly found feeding on cattails (*Typha* spp.) (ERDC, 2005, APIS). It has also been recorded feeding on many other plant species including buttonbush

(*Cephalanthus occidentalis* L.), poplars (*Populus* spp.), smartweeds (*Polygonum* spp.), willows (*Salix* spp.), sedges (*Carex* spp.), and grasses (Family – Poaceae) (Center et al. 1999).

Biology

Information from the ERDC, 2005, APIS, and Center et al. (1999), describes adult *S. henrici* as large moths having a wingspan of 34 to 45 mm (Figure 22 - Adult). Females lay flattened, grayish-white eggs in batches of from 60 to more than 150 eggs per batch. Batches can be composed of up to seven overlapping rows of eggs, with individual females having the capability of laying over 1,700 eggs.

Larvae develop through seven instar stages during an approximate 30-day period. Mature larvae are orange and brown on top, light brown underneath, and covered with hairs (Figure 22 - Larva). Larvae use silk to tie two adjacent cattail leaves together to form a pupation area. Within the pupation area, a silken cocoon is created in which the insect pupates. Total development time from egg to adult is ca. 6 to 7 weeks (Center et al. 1999).

Host-Specificity

In host-specificity studies conducted by Cassani (1985), field-collected second and fifth instar *S. henrici* larvae were placed on one of five different plant species: cattail, swamp smartweed (*Polygonum hydropiperoides* Michx.), common buttonbush (*Cephalanthus occidentalis*), torpedo grass (*Panicum repens* L.), and swamp willow (*Salix caroliniana* Michx). On swamp smartweed and swamp willow, at least 20 percent of the second and fifth instar larvae completed development through pupation. Larval mortality was 100 percent on both common buttonbush and torpedo grass, contradicting earlier literature that common buttonbush and grasses are host plants of *S. henrici*. Cattail seemed to be the preferred host plant, but Cassani (1985) did not feel that the host range of *S. henrici* was narrow enough to be considered as a biocontrol agent of cattail, at least not in south Florida.

Research/Impact

Cattail seems to be the preferred host plant of *S. henrici* (Cassani 1985). In Florida, feeding by this insect has dramatically impacted large areas of cattail stands (Center et al. 1999, ERDC, 2005, APIS).

Possible Use in Control Programs

Cassani (1985) does not feel that the host range of *S. henrici* is narrow enough to warrant its manipulation for control of cattail, at least not in south Florida. Further host range research should be conducted from other geographic locations before any attempt is made to manipulate *S. henrici* as a biological control agent.

Synclita obliteralis (Walker), Waterlily Leafcutter, (Lepidoptera: Pyralidae: Nymphulinae: Nymphulini) (Figures 23 and 24)

Figure 23. Waterlily leafcutter larva and larval damage.
(Photographs courtesy of the ERDC, 2005, APIS.)

Figure 24. Waterlily leafcutter adult. (Photograph courtesy of http://www.pbase.com/tmurray74/pyraloidea__through__pyralinae___moths, No. 4755 - Waterlily Leafcutter Moth – *Synclita obliteralis* [Murray 2005].)

General Information and History

Although adult waterlily leafcutters are moths, the larvae of most Nymphulinae are aquatic, breathing by means of gills, and feeding on aquatic plants (Figure 23 - Larva and larval damage) (Borror et al. 1976). Although the name, waterlily leafcutter, suggests that this insect feeds only on waterlilies, in actuality it feeds on more than 60 species of aquatic plants including hydrilla, waterhyacinth, waterlettuce, *Salvinia* spp. and *Myriophyllum* spp. (Center et al. 1999). In all, the total food plant list includes 23 plant families (Center et al. 1999).

Biology

Adult waterlily leafcutters are small, dark-colored moths with brown and white markings (Figure 24 – Waterlily leafcutter adult) (Lange 1956; Kinser and Neunzig 1981; Habeck 1991; ERDC, 2005, APIS). The females are the larger of the two with a wingspan of 15 to 19 mm compared to 11 to 13 mm for males (Habeck 1991). The female moths lay eggs near the edges of submersed aquatic plant leaf surfaces (Center et al. 1999). Once the eggs hatch, larvae live within a round case formed by two pieces of leaves that create an air-filled case (younger larvae may have cases filled with water) (Habeck 1991). When the larvae are ready to pupate, they spin a cocoon within their leaf case (Center et al. 1999).

Research/Impact

Information obtained from the ERDC, 2005, APIS, describes waterlily leafcutter caterpillar damage as distinct cuts on the leaves of waterhyacinth and similar damage to the floating leaves of waterlettuce. Larvae will also form small cases made from hydrilla leaf pieces where they will exist while feeding on the exposed and submersed areas of the plant (Figure 23 – Larva and Larval damage).

Possible Use in Control Programs

Synclita obliteralis is an extremely polyphagous insect, feeding on and utilizing many kinds of aquatic plants for food (Center et al. 1999). In aquatic plant nurseries, it can become a serious problem, especially on waterlilies, but aside from this, studies have not been conducted on its possible use in control programs. Because it does attack a wide variety of nuisance aquatic plants including waterlettuce, waterhyacinth, hydrilla, and salvinia, further work should be conducted to review the usefulness of the waterlily leafcutter as a potential biocontrol agent. More information is also needed on its impact to native plants, especially those used in revegetation efforts as a way to reduce hydrilla invasiveness.

4 Future Direction

To date there have not been many successful biocontrol programs using native/naturalized herbivores/pathogens to control exotic plants, however, there are several promising candidates on the horizon. Dr. Judy Shearer, ERDC, Vicksburg, MS, and Dr. Mark Jackson, USDA, ARS, NCAUR, Peoria, IL, are making great strides with the on-going research of using *Mycoleptodiscus terrestris* as a potential bioherbicide for hydrilla management. A company in Stowe, Ohio, EnviroScience, Inc., has available for sale a MiddFoil® process which includes purchasing milfoil weevils (*Euhrychiopsis lecontei*) for the management of EWM. The salvinia weevil (*Cyrtobagous salvinia*), has also been used successfully as a biocontrol agent of *Salvinia* spp. Water-primrose (*Ludwigia* spp.), although native to North and South America, is considered to be a nuisance plant in some cases, and the water-primrose flea beetle (*Altica ludoviciana*) has shown promise as a potential biocontrol agent. *Altica litigata*, another water-primrose flea beetle, has shown success by feeding on other species of *Ludwigia* - *L. octovalvis* and *L. palustris* with the added bonus of feeding on purple loosestrife (*Lythrum salicaria*).

According to Smart and Doyle (1995), to successfully restore a waterway infested with aggressive, nuisance aquatic plants, an integration of management tools is required including chemical control, biological control, mechanical control, and drawdowns. These methods must be used altogether along with an ecologically based plant competition strategy. The use of biocontrol agents would make it possible for reservoir managers to keep aquatic, nuisance plant growth in check (Smart and Doyle 1995). This would in turn allow for the introduction of native species or, if they are already present, allow them to grow without being overpowered by the exotics.

5 Summary

Future and continued research using native/naturalized herbivores/ organisms for controlling and managing nuisance aquatic plants is needed. Funding for biological control research is becoming increasingly scarce. It is becoming difficult and costly to fund scientists to explore countries where introduced, nuisance plants originate in hopes of collecting and identifying potential biocontrol agents. Studying naturalized and native herbivores and pathogens that impact nuisance aquatic and wetland plants would increase the number of potential biocontrol agents that could be incorporated into invasive plant management programs. The groundwork has been laid for conducting future biocontrol research and experimentation. Although not all of the native and naturalized organisms discussed can be successful, the information and expertise is now available for potential insects and pathogens to be collected, analyzed, and studied. A continuation of the work that has been started is needed to make available for the future more successful native biocontrol agents.

Research is being conducted by ERDC scientists to identify naturalized and /or native herbivores of aquatic plants in an effort to develop alternative management strategies through an understanding of the agents' biology and ecology. Some of the native species that are showing promise as biocontrol agents include *Altica* spp. for water primrose, *Donacia* spp. for American lotus, and *Euhrychiopsis lecontei* for Eurasian watermilfoil control. Naturalized species with possibility include *Cyrtobagus salviniae* for common and giant salvinia, and *Parapoynx diminutalis* for hydrilla.

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14. ABSTRACT
Research is being conducted by U.S. Army Engineer Research and Development Center (ERDC) scientists to identify naturalized and/or native herbivores of aquatic plants in an effort to develop alternative management strategies through an understanding of the agents' biology and ecology. Some of the native species showing promise as biocontrol agents include *Altica* spp. for water primrose, *Donacia* spp. for American lotus, and *Euhrychiopsis lecontei* for Eurasian watermilfoil control. Naturalized species with possibility include *Cyrtobagus salviniae* for common and giant salvinia, and *Parapoynx diminutalis* for hydrilla. Information is presented herein for selected native and naturalized agents that may potentially be used to impact and manage all types of aquatic and wetland plant species including introduced, naturalized, and native species. Native and naturalized insect herbivores and fungal pathogens discussed include: *Acanthoscelides quadridentatus*, *Acentria ephemerella*, *Altica* spp., *Cyrotobagous salviniae*, *Donacia* spp., *Euhrychiopsis lecontei*, *Hydrellia bilobifera* Cresson, and *H. discursa* Deonier, *Mycoleptodiscus terrestris*, *Ostrinia penitalis*, *Parapoynx diminutalis*, *Pergaster cretura*, Simyra *henrici*, and *Synclita oblieralis*.

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